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Metals Demand and the Canadian Metal Industry: Structural Changes and Policy Implications

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Foreword

The subject of metals demand and metals prices is a moving target, one that has seen a remarkable turnaround in recent years from slack demand and low prices to tight supplies and record high prices. Using statistics and examples derived from before the recovery of 1988 and 1989 the author has nevertheless identified enduring trends. He warns industry decision-makers and marketing experts against assuming that markets will remain strong without conscious and deliberate efforts at marketing and product development.

The Centre for Resource Studies is pleased to present this study, as part of its program of research and communication in issues of mineral policy and mineral economics.

Views expressed are those of the author, and do not necessarily represent the views of the Centre for Resource Studies or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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With these expressions of gratitude go our personal affirmations of responsibility for this study.

Carmine Nappi
Ecole des Hautes Etudes Commerciales
Montreal, October 1988

Summary

This study investigates the reasons for the atrophy of demand for metals, examining in detail both cyclical and structural causes. It comes to the conclusion that in OECD countries in general, the latter causes have been more significant than the former ones in the decline of the demand for aluminum, nickel and zinc. In the main market for Canadian metals exports, the United States, structural causes — the substitution of metals by other materials, the growing use of metal-saving technologies, inter- and intra-sectoral shifts taking place in the economy, etc. — predominate for all five metals under study. This implies that given declining intensity of use, the economy must now expand by between one and six percent a year, depending on the metal and the geographical area, just to keep metal consumption from falling.

Given such findings, the implications for the strategies of metallurgic firms and for government policies are straightforward. Closer relations should be forged between metals producers and consumers. Increased spending on research and development is needed in order to improve the competitiveness of the existing products and to develop new markets. More flexible pricing policies are required in order to prolong the industry's phase of maturity. Although we reject the idea that traditional metal producers should begin a wide-scale diversification of their production, they would be well advised to differentiate their products and develop new ones specifically designed, engineered and fabricated to meet their customers' increasingly exacting specifications. Government policy should be as sensitive to the consequences of technological development on the marketing of metals as to its effects on process technologies.

Finally, and perhaps the most important implication, it is imperative that company directors and government officials recognize that we are no longer living in a period when metals practically sold themselves or were easily sold without any sophisticated marketing strategy.

Résumé

Cette étude examine l'importance relative des causes cycliques et structurelles de l'atrophie observée dans la demande des métaux. Elle conclue que pour l'ensemble des pays de l'OCDE les variables structurelles s'avèrent plus importantes que les variables cycliques pour expliquer l'atrophie dans la demande d'aluminium, de nickel et de zinc. Pour les Etats-Unis, le plus important débouché des exportations canadiennes de métaux, les causes structurelles (la substitution des métaux par d'autres matériaux, l'utilisation croissante de technologies moins intensives en métaux, les transferts inter et intra-sectoriels observables dans une éconmie, etc.) prédominent pour tous les cinq métaux à l'étude. La diminution tendancielle de l'intensité d'utilisation des métaux implique que l'économie doit expérimenter un taux de croissance variant entre 1 et 6% par année (dépendant des métaux et des marchés géographiques à l'étude) uniquement pour empêcher la consommation de métaux de diminuer.

Les implications de ces résultats pour les stratégies des entreprises métallurgiques et pour les politiques publiques peuvent être résumées ainsi. Des relations plus soutenues et plus serrées doivent être tissées entre les producteurs et les consommateurs de métaux. Il faut augmenter la compétitivité de la gamme courante de produits et en développer de nouveaux grâce à des dépenses accrues en recherche et développement. Des politiques de prix plus flexibles s'avèrent nécessaires si nous désirons prolonger la phase de maturité de l'industrie. Même si nous ne recommandons pas une diversification sur une grande échelle de la production, nous croyons souhaitable que les producteurs de métaux traditionnels différentient davantage leur production en développant et en fabriquant des produits qui répondent mieux aux spécifications précises des consommateurs. Les politiques gouvernementales doivent demeurer sensibles non seulement aux conséquences des changements technologiques sur les procédés de production mais aussi à leurs effets sur la mise en vente des métaux.

Mais l'implication la plus importante de cette étude demeure le besoin pour les dirigeants d'entreprises et les autorités gouvernementales d'admettre que nous ne vivons plus à une époque où les métaux se vendaient tout seul ou du moins sans l'aide d'une stratégie sophistiquée de mise en marché.

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1. Introduction

From the end of the second world war to the mid-1970s, the main concern of the metals industry was to assure sufficient production to respond to an ever-growing demand for its products. As demand was correlated to economic activity, and the relationship between the two seemed relatively stable, it came to be believed that demand for metals was exogenous to the firm, and less subject to control than production.

Thus, most metal producers accepted without question that developing new uses for metals, as well as testing and confirming that a particular metal and/or alloy was the right material for a given application, was the task of consumers. Their own role was to ensure continuous deliveries at profitable prices; to produce for an anonymous market, not for specific consumers.

Scholars interested in questions of resources showed a similar orientation. Their research interests reflected greater concern with supply and production of metals than with demand or consumption. Works written during this time addressed such questions as: optimal rates of extraction from mines; the viability of cartels or other less formal associations of producers and their effects on prices and quantities of metals; the determinants of secondary supplies of metals and their effects on the prices of primary metals; the consequence for the structure of the metals industry of the arrival of new producers and thus of an increase in the number of centres of decision; and so on.

It may be no surprise that little interest was shown in the evolution of metals consumption at a time when consumption rates were increasing at the same or at a faster pace than the gross domestic product (GDP). During the period 1960-73, the annual growth rate of the GDP for most countries of the Organization for Economic Cooperation and Development (OECD) was 4.8 percent. It was, in most cases, matched or surpassed by the annual rates of growth in the consumption of the principal metals: aluminum 8.6 percent; nickel 6.4 percent; steel 5.3 percent; zinc 4.3 percent; copper 3.8 percent; and lead, the weakest, 3.4 percent.

Metals consumption was growing so fast that suppliers felt little need to pay much attention to their relationships with their clients. Thus, producers of ores and metals failed to notice that the structure of their industry was gradually changing and that they should have been adapting to a new competitive situation, characterized by a constant evolution in consumer needs, the development of new products and competition among different materials.

Around the middle of the 1970s, consumption of the principal metals ceased to increase at its previous rate, and in some cases even began to diminish. At first this decrease in demand caused little concern, being attributed to the general economic downturn experienced by western countries after the petroleum price shocks of 1973, 1975 and 1979. However, during the first half of the 1980s, concern began to set in: the situation of excess supplies and relatively weak prices persisted in the metals industry, despite one of the longest periods of economic revival of the post-war era. The theory that this stagnation was linked to structural (and not just cyclical) causes began to gain ground. There was a need to explain why in the period 1973-87 the growth of consumption of the principal metals became divorced from that of the gross domestic product (GDP). While the GDP of the OECD as a whole grew at that time by 2.5 percent per year, consumption of the principal metals grew by only 0.9 percent annually in the case of aluminum, 0.7 percent for copper, 0.5 percent for lead, 0.8 percent for nickel, and -0.2 percent for zinc. In the United States, in spite of an annual growth rate for the GDP of 2.5 percent, consumption of the principal metals showed a negative growth, except in the case of copper, which grew at a negligible 0.5 percent.

How can we explain this sudden change in the evolution of the two rates of growth? Do metals, like manufactured goods, have predictable life cycles? Are they now past the stage of expansion and entering the gerontic stage or even, in some cases, the stage of contraction? Or is the evolution of metals consumption better explained by the hypothesis of intensity of use, which links the evolution of a metal consumption per unit of GDP to that of a given region's level of economic development?

If we agree that the atrophy in the demand for metals is largely explainable by structural factors, how can we delineate and describe their effects? Has there been a change in the material composition of products — the amount of aluminum, zinc and other materials used in the production of individual products such as automobiles? Should that change be attributed to the substitution of materials, or to the use of new resource-saving technologies? What role, in each case, is played by the evolution of relative prices? What is the effect of a change in the mix of goods and services produced by the economy on the demand for metals? Even more important, what do these changes imply for the mining policies of governments and, more particularly, for the strategies of mining and metals firms? In fact, what strategies are really available to them? A more aggressive research and development policy, centred more on product development than on the production process? A lateral diversification of their production activities, which recognizes that they are in the materials business and not in the metals business alone? What role can government play in a context where it is necessary to stimulate the demand for metals?

These are some of the questions we will consider here. In the second chapter of this study we will present the basic facts — in particular, the evolution over time within the OECD and its member countries of the consumption of five metals that are important to Canada as exports: aluminum, copper, nickel, lead and zinc. Having established the facts, we will try to explain them by looking, in the third chapter, at several possible approaches. The fourth chapter will focus on the main determinants of the evolution of metals demand: the index of industrial activity; the material composition of products; and the product composition of income. We will present some statistical evidence regarding their significance, and analyze in depth some of the principal end-use markets of the metals being studied. The fifth chapter will deal with the policy implications of the atrophy of the consumption of metals. In particular, our attention will be focused on government mining policies and the strategies of metal-producing firms with regard to price policies and horizontal diversification. The last chapter will present the conclusions of the study.

2. Trends in Metals Demand

Our aim is to determine whether a break can be detected in the evolution of the consumption levels of the metals that play a major role in the Canadian economy, a break that diverges from the evolution of the GDP of the principal export markets. Let us begin by defining some of our terms and the time and area covered by the study.

Definitions

Which are the Metals under Study?

This study looks at the principal nonferrous metals (excluding precious metals): aluminum, copper, nickel, lead and zinc. These metals were chosen for several reasons. First, in 1987 the value of exports of these five metals was almost $4 billion, representing 60 percent of Canadian exports of nonferrous metals. (The balance consisted primarily of precious metals). In 1988, the value of exporting the five metals will be even higher, since the annual growth rate of the GDP in OECD countries will be much higher than the previous year, nearly reaching the 4 percent level. Even if the total of these exports comes to less than 4 percent of Canada's exports overall, this will be higher than exports of metal ores, including concentrates and scrap, and of Canadian crude petroleum. These metals are clearly not marginal products, and their significance appears even greater when we consider their role in the economies of several Canadian regions.

Second, Canada is among the five most important producing countries of each of these metals and/or the ores from which the refined metals are made. Third, for these five metals there exist statistical data sufficiently homogeneous and covering a long enough period of time to enable us to study international variations in their consumption.

Measurement of Metals

The demand for a metal can be measured at different points along the chain of production. Thus, we can consider the demand of smelters and refiners for concentrates or for the metal in scrap; the demand on the part of fabricators for the refined metal, or for secondary metal; the demand of manufacturers for the metal in fabricated and semifabricated products; and, finally, the demand of consumers for the metals contained in the final goods they purchase. This study will focus mainly on the fabricators' demand for finished but unwrought metal at the first stage of processing.

However, as we know, demand for a metal at any given period of time usually consists of two components: the amount required by fabricators for transforming into semimanufactured products (what is designated "consumption"), and the amount demanded in relation to changes in inventories. Our study will consider statistical data relating only to the first component, that is, the quantity of unwrought metal available for consumption, without considering whether the products manufactured from it are consumed at home or exported. These figures are determined for each of the countries included in this study by adding to the domestic production of an unwrought metal the imports of that metal and by subtracting from it exports and net additions to inventories.

The question remains whether this measure of apparent consumption, as reported in most time series, should or should not exclude consumption of secondary metal. For now, let us just note that the statistical data used in this study came from Metallgesellschaft.[1] In the case of aluminum, nickel and zinc, these figures relate to primary metal and completely ignore consumption of secondary metal. However, in the case of copper and lead, the method of compilation is not so clear. For copper, scrap used directly by brass mills is not included in the figures, while scrap used to produce refined copper is. In the case of lead, secondary lead is included in the production of refined lead.[2] The bias in the estimation of total consumption induced by this treatment of the secondary consumption will be addressed later on in appendix A.

Two other statistical problems should be noted. First, as stated earlier, quantities of metals demanded for inventory purposes should be excluded from the time series. However, this is not done for certain countries of the OECD. Furthermore, when net additions to inventories are excluded, this applies only to visible inventories. The figures do not take into account unreported variations in inventories held by various agents — in particular, variations in certain economic or strategic stockpiles. Second, the consumption of refined metal in an economy should be distinguished from its overall "metal absorption," which is defined as the total domestic usage of a metal in final consumer and investment goods. The difference between the two consists of the metal content in net trade of semimanufactured and finished products. Although it may be very difficult to measure the metal absorption of an economy, it should be noted that the consumption of a refined metal as defined above is a clearly delimited concept and is not equivalent to the total consumption of the metal.

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[1] Metallgesellschaft Aktiengesellschaft, *Metallstatistik*, (Frankfurt Am Main: Metallgesellschaft AG), various issues.

[2] Included in the production of refined lead are soft lead at primary and secondary plants and antimonial lead at primary and secondary plants.

Time and Space Coverage

Our study covers the period 1950-87, an interval sufficiently long to enable us to distinguish the effects of variations linked to specific circumstances from those reflecting more profound changes in the economy. Had we used a longer time series, including the period between the two world wars, we would perhaps have been able to test the hypothesis that the high rates of growth in the consumption of metals during the period 1945-73 were simply the consequence of European and Japanese economic reconstruction. The decrease in growth after 1973 can thus be perceived as a return to the historical trend that existed before the second world war. However, uniform statistical data for that time are not available for the five metals considered in the study.

Because the Canadian market is small, producers of nonferrous metals are obliged to export much of their production to foreign markets. As a result, domestic production levels are largely determined by the levels of consumption of major clients. Who are the main international consumers of Canadian nonferrous metals? In 1987, 95 percent of these exports were absorbed by the member countries of the OECD. The major individual consumers are: the United States, which absorbed more than 70 percent of Canadian exports of the nonferrous metals under study, the EEC,[3] 10 percent; particularly the United Kingdom, the Federal Republic of Germany (West Germany) and France; and Japan, almost 5 percent.

Analysis of the Evolution of Consumption

The evolution of the consumption of the five metals under study during the years 1950-87 by the member countries of the OECD is illustrated in figure 1. In most cases, the evolution profile follows a particular pattern: a relatively slow growth in consumption during the 1950s, an acceleration of growth during the 1960s and early '70s, and then, a sudden break. Although the exact year when the break occurred differs for the metals (1973 for copper and zinc; 1974 for aluminum and nickel; 1977 for lead), what is common to all is that the break was major. Fifteen years later, consumption is not very different from the levels of the early 1970s. In fact, the difference between the current levels of consumption (the shaded area) and those that would have been reached had consumption continued to increase after 1973 at the same rate as during the period 1950-73 (the dotted line) has continued to grow larger. In some cases (aluminum, nickel, zinc), this difference is almost equal to the present level of consumption. The stagnation is persisting in spite of the fact that the real GDP

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[3] We refer here to the EEC as composed of the following nine countries or groups of countries: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands and the United Kingdom.

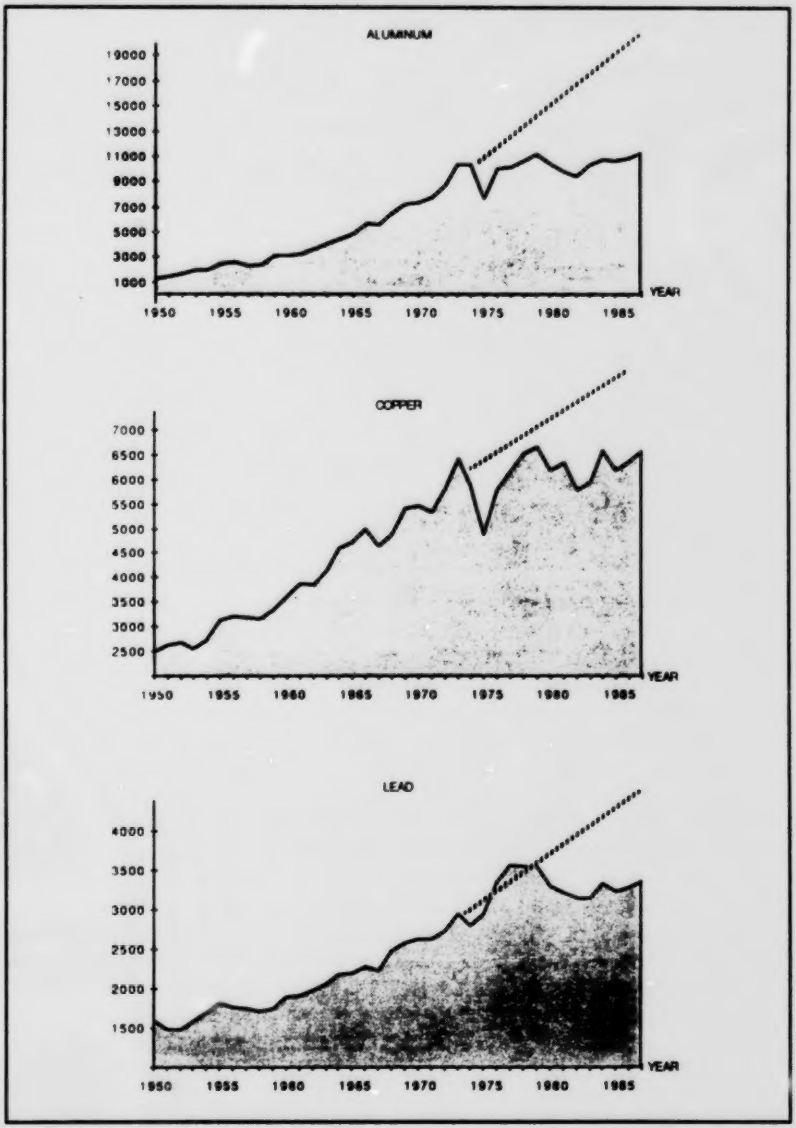
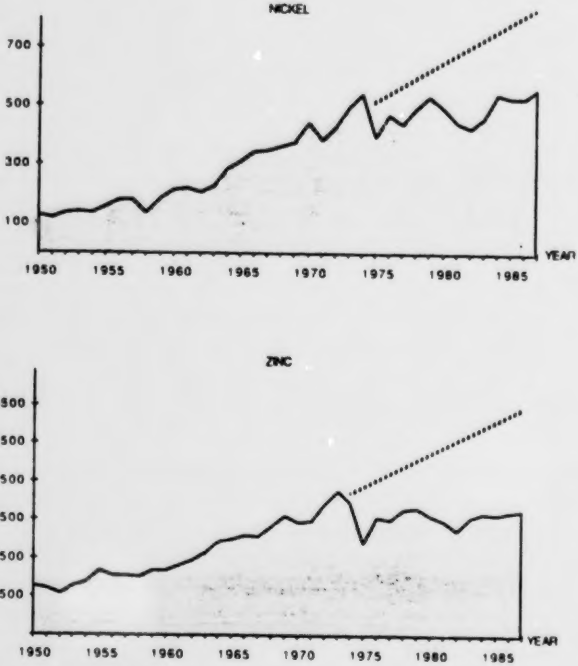


Figure 1. OECD[a] consumption of major nonferrous metals, actual and trends, in thousands of tonnes, 1950-87

Figure 1 (continued)



[a] OECD: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

Source: figure derived from: Metallgesellschaft Aktiengesellschaft, *Metal Statistics* (Frankfurt Am Main: Metallgesellschaft AG), various issues covering the period 1950-86; World Bureau of Metal Statistics, *World metal statistics* (Edgbaston, Birmingham, England), various monthly issues covering the year 1987.

(for the whole OECD) has been growing at 2.5 percent per year. Thus, we can hardly say that the atrophy of the consumption of the metals is a passing phenomenon that will correct itself when the economy recovers. It appears more and more to be a reflection of profound structural change, rather than a cyclical effect.

Does the consumption profile of the metals being studied found for the OECD as a whole (moderate growth during the 1950s, strong growth during the 1960s and early 1970s and stagnation after that) also hold for each country individually? Is the pattern more pronounced for some metals than for others? Figures 2 and 3 and table 1 answer these questions. Figure 2 shows the evolution of the consumption of the five metals within three large economic blocs: the United States, Japan, and the EEC. Figure 3 provides the same data for the three largest members of the EEC: the United Kingdom, West Germany, and France. Table 1 shows the annual growth rates of the consumption of the metals for each of the seven above-mentioned countries or groups of countries during three periods: 1950-60, 1960-73 and 1973-87. In addition, it gives us a useful basis for comparison by also providing the annual growth rates of the GDP for each of the markets considered and, when possible, for each of the selected periods.

The information contained in these figures and table can be summed up as follows.

- The break in the evolution of metals consumption in the member countries of the OECD, which we referred to earlier, is confirmed to varying extents for all the countries considered and for each of the metals being studied. The mid-1970s appear to be a turning point in the long-term evolution of metals demand. For the period 1973-87, the rates of annual growth in the consumption of the five metals are between two and ten times lower than for the years 1960-73.
- If we look just at aluminum, we find that the United States is the only OECD country to have registered a higher growth of consumption during 1960-73 than during the 1950s. For the other countries, the reverse is true. This suggests that the sudden decline after 1973 in the growth rate of their aluminum consumption was a continuation of a long-term trend, the origins of which go back to 1950. Another difference appears in the period 1973-87. There we see that the annual growth rates of aluminum consumption in West Germany, France and Japan stabilized, after falling to about 2 to 3 percent, while in the United States and the United Kingdom they were negative. Finally, let us note that the aluminum consumption seems to have been less adversely affected in West Germany and France than in the other countries considered. In spite of having fallen more than 60 percent, it grew more rapidly in each case than the GDP.

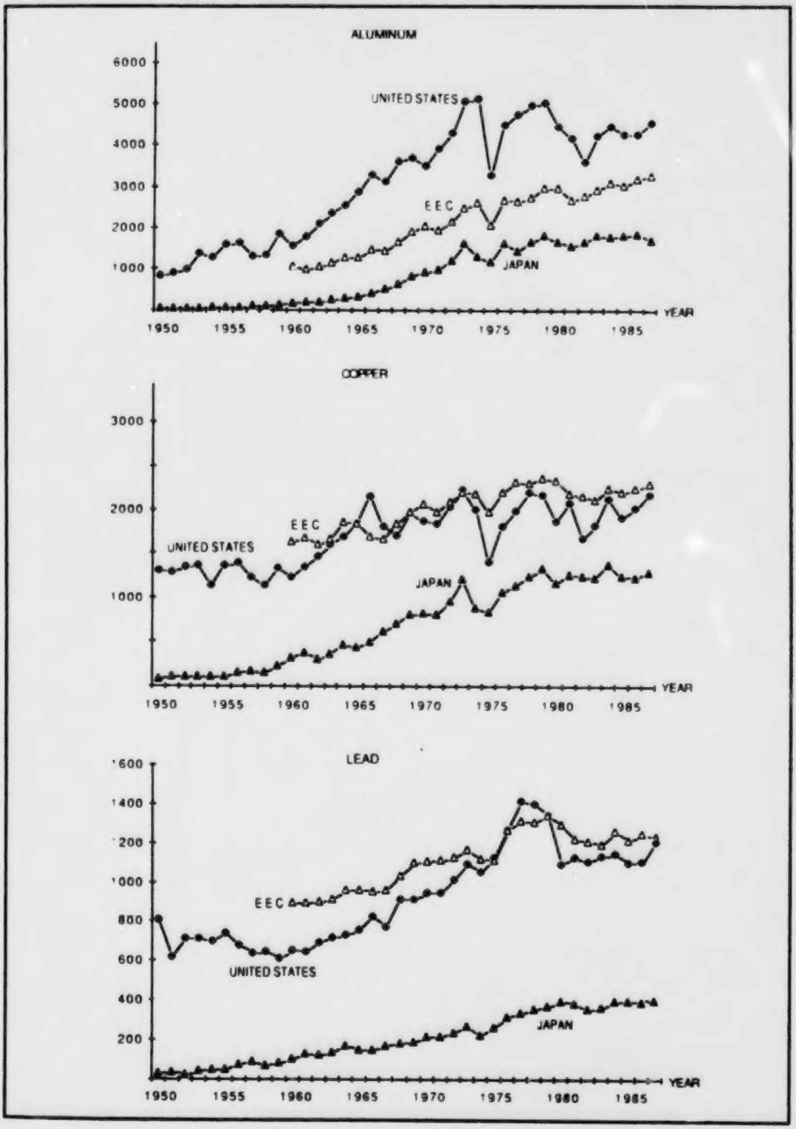
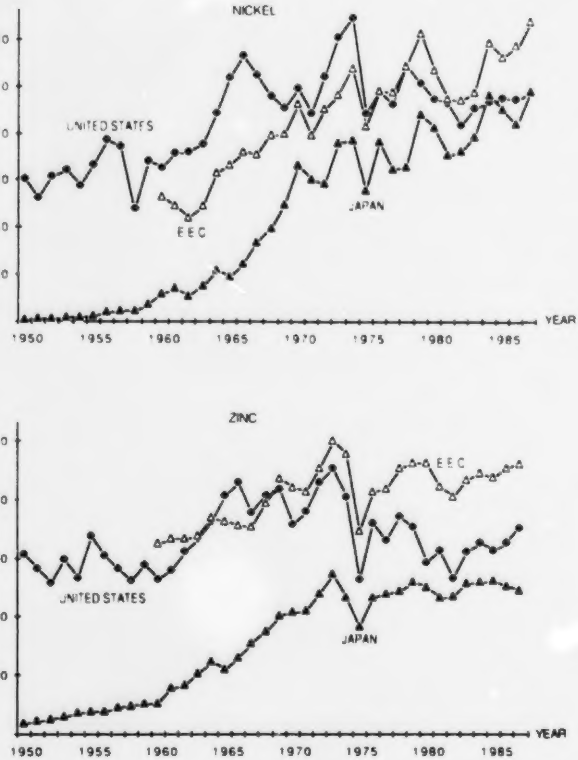


Figure 2. Aluminum, copper, lead, nickel and zinc consumption for the United States, EEC[a] and Japan, in thousands of tonnes, 1950-87

Figure 2 (continued)



[a] EEC: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands, United Kingdom.

Source: figure derived from Metallgesellschaft Aktiengesellschaft, *Metal statistics* (Frankfurt Am Main: Metallgesellschaft AG), various annual issues covering the period 1950-86; World Bureau of Metal Statistics, *World metal statistics* (Edgbaston, Birmingham, England), various monthly issues covering the year 1987.

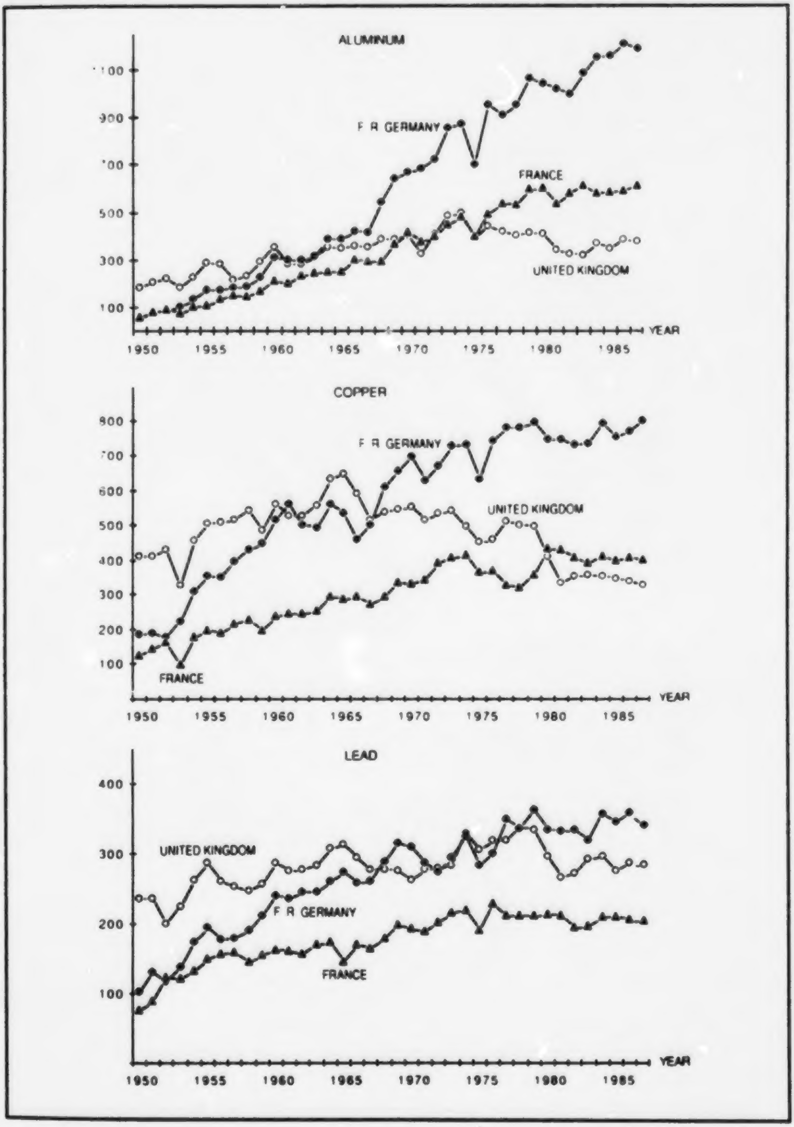
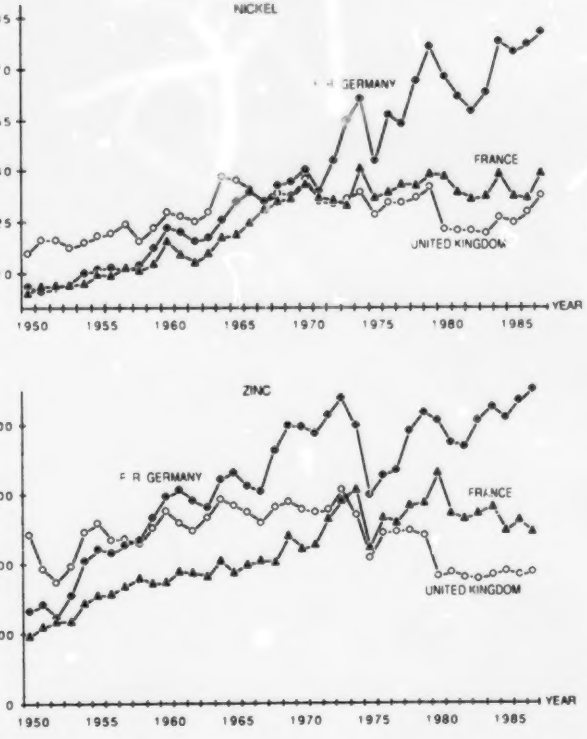


Figure 3. Aluminum, copper, lead, nickel and zinc consumption for the United Kingdom, France and Federal Republic of Germany, in thousands of tonnes, 1950-87

Figure 3 (continued)



Source: figure derived from Metallgesellschaft, *Metal statistics* (Frankfurt Am Main: Metallgesellschaft AG), various annual issues covering the period 1950-86; World Bureau of Metal Statistics, *World metal statistics* (Edgbaston, Birmingham, England), various monthly issues covering the year 1987.

Table 1:
Percentage Annual Growth Rates[a] of Metal Consumption (C) and GDP, 1950-87

	1950-60		1960-73		1973-87	
	C	GDP	C	GDP	C	GDP
OECD				4.8		2.5
Aluminum	7.6		8.6		0.9	
Copper	3.5		3.8		0.7	
Lead	2.0		3.4		0.5	
Nickel	4.9		6.4		0.8	
Zinc	2.9		4.3		-0.2	
United States		3.3[b]		3.9		2.5
Aluminum	6.1		7.5		-0.8	
Copper	-0.5		3.3		0.5	
Lead	-1.6		4.0		-0.3	
Nickel	1.3		3.3		-1.4	
Zinc	-0.5		3.1		-1.4	
EEC[c]				4.4		1.8
Aluminum			7.1		2.0	
Copper			2.3		0.2	
Lead			2.3		0.3	
Nickel			5.5		1.6	
Zinc			3.1		0.0	
Japan		7.2[d]		8.9		3.9
Aluminum	17.4		16.9		1.9	
Copper	13.3		10.2		1.9	
Lead	13.3		6.4		3.0	
Nickel	26.4		14.4		2.3	
Zinc	10.0		10.4		0.6	
United Kingdom		2.5[d]		2.9		1.4
Aluminum	5.1		2.6		-2.2	
Copper	3.6		-0.4		-3.7	
Lead	2.0		-0.4		-0.9	
Nickel	4.0		1.2		-1.4	
Zinc	2.5		0.7		-3.5	
Federal Republic of Germany		6.6[d]		4.4		1.9
Aluminum	14.0		8.6		2.8	
Copper	10.8		2.8		0.6	
Lead	7.2		1.8		1.1	
Nickel	13.8		6.7		2.9	
Zinc	8.2		3.3		1.3	

Table 1 (continued)

France		4.9		5.3		2.0
Aluminum	11.3		6.1		2.2	
Copper	6.2		4.0		0.6	
Lead	5.9		2.3		-0.3	
Nickel	12.3		6.2		0.2	
Zinc	5.9		3.4		-0.5	

[a] Annual growth rates have been obtained by dividing the slope of the trend line by the mean for each corresponding period. The consumption of metals was measured in thousand tonnes and the GDP in million constant 1980 U.S. $.

[b] 1950-59 period.

[c] EEC: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands, United Kingdom.

[d] 1953-60 period

Source: table derived from: Metallgesellschaft Aktiengesellschaft, *Metal Statistics* (Frankfurt Am Main: Metallgesellschaft, AG), various issues; World Bank, Data Tape, 1987 ed.; International Monetary Fund, *International Financial Statistics*, Vol. XXXI, No.5, May 1978 (annual data 1953-77); Goldman Sachs, *The International Economics Analyst*, issue no. 7/8, vol. 5, July/August 1988.

- Copper resembles aluminum, in that the profile of growth found for the whole OECD[4] is echoed among individual countries only by the United States. In the other countries, the strongest growth occurred during the 1950s. In fact, in the United Kingdom, copper consumption already showed a negative growth in 1960-73. During the 1973-87 period, the annual growth rates of copper consumption outside the United Kingdom were modest but positive (ranging between 0.1 percent and 0.7 percent, except in Japan, where the rate reached 1.9 percent). Unlike the case of aluminum, there is no country where copper consumption grew at a higher rate than the GDP.
- Lead differs from the other metals by the weak growth of its consumption. During 1960-73, consumption grew by under 2.3 percent per year, except in the United States and Japan, where the rates were 4 percent and 6.4 percent respectively. That rate was already two or three times lower than that reached during the preceding decade. The years 1973-87 were a difficult period for lead producers, as consumption showed a negative growth in the United States, the United Kingdom and France, a weak growth of 1.1 percent annually in West Germany, and a 3 percent annual growth in Japan, the highest in that period of any of the metals studied. The situation in Japan was the

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[4] Moderate growth during the 1950s, strong growth during the years 1960-73, then stagnation.

reverse of 1960-73, when Japanese consumption of lead increased more slowly than that of other metals.

- Nickel consumption increased rapidly during 1950-73, with the increase being more pronounced (except in the United States) at the beginning of that period than at the end. During 1960-73, nickel consumption, like that of aluminum, grew faster than the national economy in Japan, West Germany, and France. After the mid-1970s, nickel consumption fell off significantly, to show a negative growth in the United States and the United Kingdom, and in Japan, a growth half as fast as that of the national economy. Only in West Germany did nickel consumption grow faster than the GDP, although still more slowly than during the preceding period.
- During 1960-73, zinc consumption never increased by more than 3.4 percent per year. The only exception is Japan, where consumption of all the metals (apart from lead) grew more rapidly at that time than the GDP. As of the mid-1970s, the annual growth rate of zinc consumption continued to decline in the countries where it had already been falling for a quarter of a century (France, West Germany, the United Kingdom), while in those where it had peaked during 1960-73 (the United States, Japan), it fell abruptly. This means the growth was negative for the all OECD members with the exception of Japan and West Germany, where it settled at about 1 percent per year. In most of the countries under study, the peak levels of zinc consumption attained in 1973 or 1974 have never been surpassed.

These are the facts we have to explain, along with their implications for government economic policies and the strategies of mining and metals firms. Beginning with the mid-1970s, the levels of consumption of aluminum, copper, lead, nickel and zinc ceased to increase at the same pace as they had during the two preceding decades; in some cases, they even fell. The annual growth rates of the consumption of the metals continued the decline that had begun in the early 1950s or 1960s.[5] Some attempts to explain these occurrences will be the subject of the next section.

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[5] The general pattern that, except for the United States and for zinc in Japan, growth rates for individual countries fell over the whole period, while the pattern for the OECD aggregate was different, can be explained by the large size of the United States and by Japan's growth into a large economy during the period under study.

3. Explaining the Atrophy in Metals Demand

The atrophy of the demand for the principal metals, the sudden drop in the annual growth of their consumption, which became apparent after the mid-1970s has been explained in various ways. Some people have pointed to the fact that economic activity in the countries under study decreased at the same time; others have suggested that some of the metals had reached the last stage of their life cycle. Malenbaum's hypothesis links the decrease in the intensity of use of a metal (its consumption in volume per unit of GDP) to the stage of development of an economy. Other theories which combine several of these approaches have also been proposed. We will examine all these approaches to see which one proves most convincing.

The Economic Cycle and the Demand for Metals

The first approach considers the role of economic activity in the atrophy in metals demand. The effect of variations in the gross domestic product (GDP) or in the gross domestic investment (GDI) on metals demand has been widely recognized and analyzed. According to this view, if demand for the principal metals has suddenly stopped growing, or is declining at an accelerating rate, the explanation must be sought in macroeconomic aggregates. When the GDP or GDI resumes its normal growth, metals consumption will do the same.

Will it really? Even if there exists a relationship between the consumption of the principal metals and various measures of economic activity, is that relationship stable over time? Will one unit of growth in GDP or GDI produce as much growth in metal consumption as it had before? Is the atrophy of the demand for metals solely a cyclical phenomenon, with no structural basis? One way to attempt a reply to these questions is to compare the annual growth rates of metals consumption and those of economic activity, as we have done in table 1. The table shows that during 1950-60, consumption of all the metals grew at a faster rate than the GDP in all OECD countries except the United States, where this was true only of aluminum.

During 1960-73, the relationship between metals consumption and the evolution of economic activity changed; consumption of metals (copper, lead and zinc but not aluminum and nickel) grew less rapidly than the GDP in the whole OECD, and in particular in France, West Germany and the EEC. In the United States, aluminum and lead were the exceptions. Japan and the United Kingdom were the two extremes: in Japan, consumption of all the metals (except lead) grew faster than economic activity; in the United Kingdom, the reverse occurred.

During 1973-86, the difference in growth between metals consumption and economic activity grew even wider. In the OECD generally, and the United States, Japan and the United Kingdom in particular, consumption of all the metals grew more slowly than the GDP. The only exceptions to this overall trend were aluminum and nickel consumption in West Germany, and aluminum consumption in France.

The differences in the two rates of growth cast doubt on the theory that a stable relationship exists between metals consumption and economic activity, and that a decline in the latter inevitably occasions an equivalent decline in the former. Table 1 shows that, while in the whole OECD the annual growth rate of the GDP fell by 50 percent between 1960-73 and 1973-86, the annual growth rate of the consumption of the principal metals fell much more (between 80 percent and 105 percent) during the same period. If we look at the relationship between the GDP and metals consumption in individual countries, the same observation holds true. We can thus conclude that the decrease in the growth of the GDP does not in itself account for the observed decline in metals consumption and that the atrophy of the demand for the principal metals cannot be considered a purely cyclical occurrence.

We are basing our conclusion on a rather arbitrary comparison of the average annual growth rates of the two variables calculated for our chosen periods of time. A more reliable approach would be to compare the evolution of metals consumption and economic activity over the long term. For that, we need to determine the index of the intensity of use (IU), which shows consumption (C) of a metal (measured in tonnes of metal consumed) per unit of GDP or GDI (measured in million constant U.S. 1980 dollars). Figures 4 and 5 show the value of this index for each of the countries and metals under study for the period 1960-87, while table 2 shows the mean value, the trend and the annual growth rate of the index of intensity of use of the metals.

The information contained in these figures and table can be summed up as follows.

- The mean value of the intensity-of-use index of copper, lead and zinc in 1973-87 was lower than it was in 1960-73, which suggests consumption of these metals declined more rapidly during the last thirteen years than did the index of industrial activity. The decrease of the index of intensity of use occurred at an accelerating rate, which means that a given increase in income translated itself into an ever-smaller increase in the consumption of the metals; or, conversely, a given decrease in income entailed an ever-greater drop in their consumption.
- The negative growth of the intensity-of-use index of copper, lead and zinc is not a new occurrence. During 1960-73, the slope of the trend line was

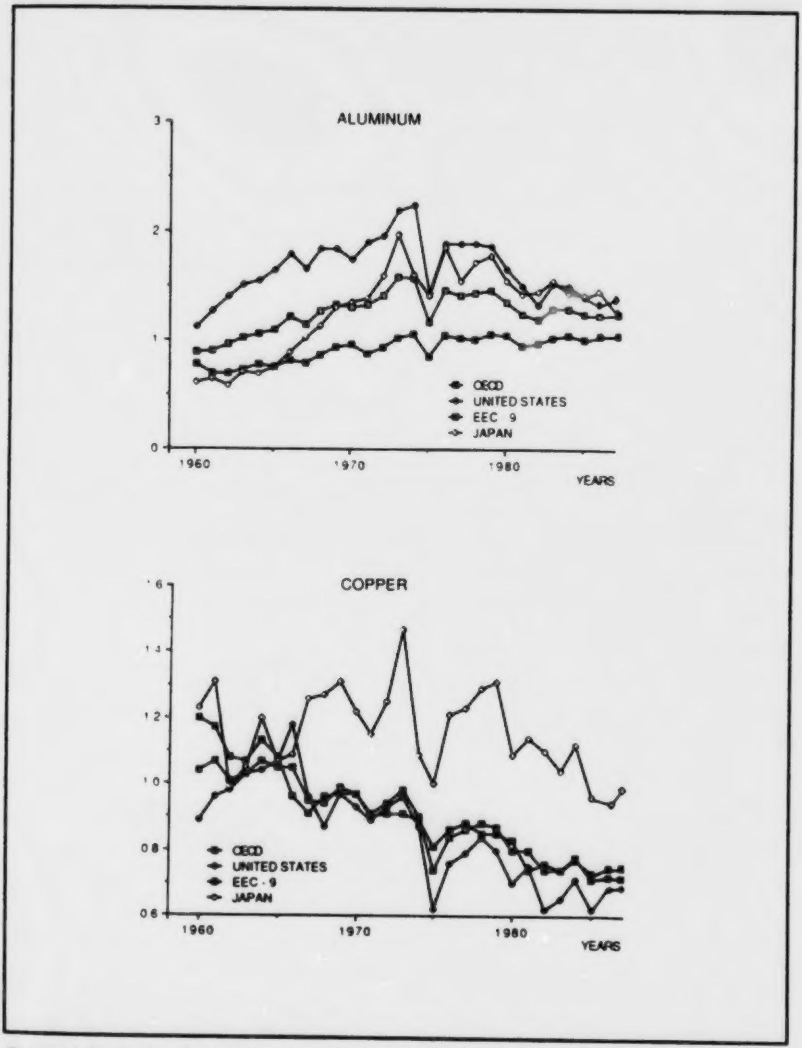
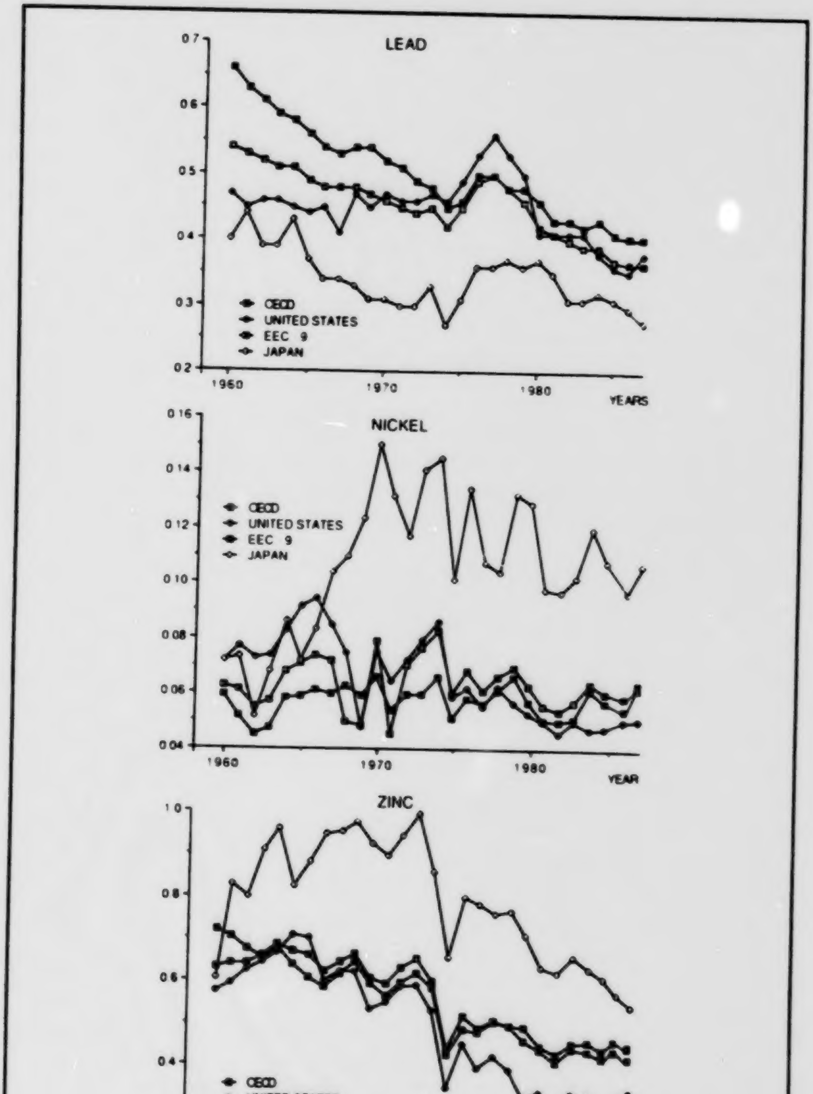


Figure 4. Intensity of aluminum, copper, lead, nickel and zinc use for OECD, United States, Japan and EEC: 1960-87 (tonnes of metal consumed per million constant U.S. 1980$)

Source: **table derived from sources cited at table 1.**


LEAD
0.7
0.6
0.5
0.4
0.3
0.2
OECD
UNITED STATES
EEC 9
JAPAN
1960
1970
1980
YEARS
NICKEL
0.16
0.14
0.12
0.10
0.08
0.06
0.04
OECD
UNITED STATES
EEC 9
JAPAN
1960
1970
1980
YEAR
ZINC
1.0
0.8
0.6
0.4
0.2
OECD
UNITED STATES
EEC-9
JAPAN
1960
1970
1980
YEARS

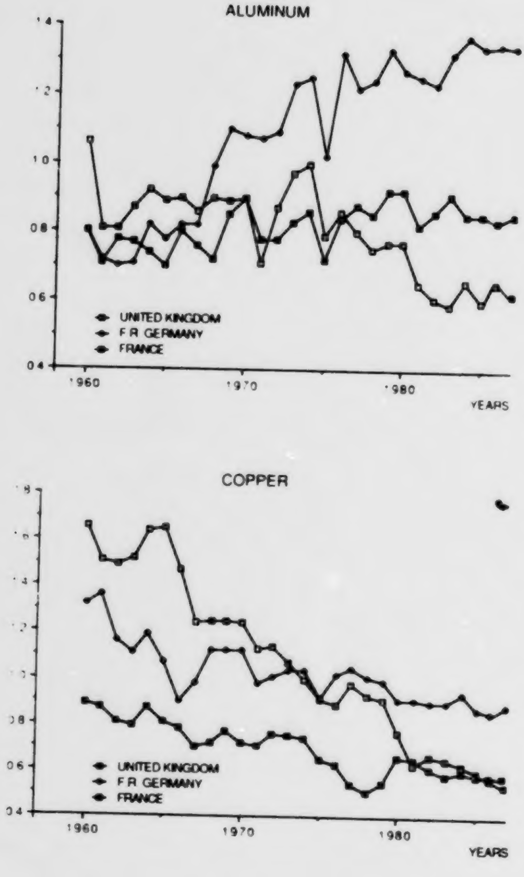


Figure 5. Intensity of aluminum, copper, lead, nickel and zinc use for the United Kingdom, Federal Republic of Germany and France: 1960-87 (tons of metal consumed per million constant U.S. 1980$)

Source: table derived from sources cited at table 1

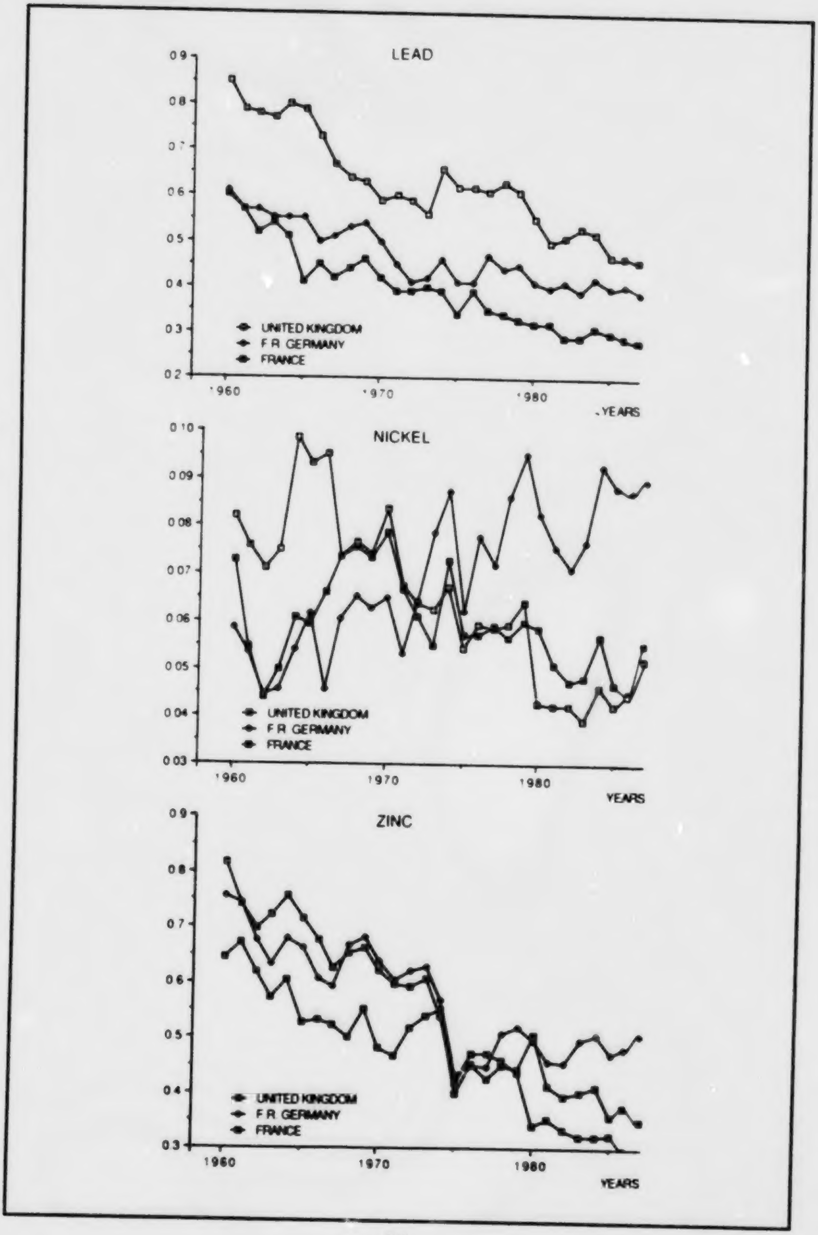

LEAD
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
UNITED KINGDOM
F.R. GERMANY
FRANCE
1960
1970
1980
YEARS
NICKEL
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
UNITED KINGDOM
F.R. GERMANY
FRANCE
1960
1970
1980
YEARS
ZINC
0.9
0.8
0.7
0.6
0.5
0.4
0.3
UNITED KINGDOM
F.R. GERMANY
FRANCE
1960
1970
1980
YEARS

Table 2:

Arithmetic Mean ($\overline{X}$), Slope of the Trend Line (t) and Annual Growth Rate ($\dot{g}$) of Intensity of Aluminum, Copper, Lead, Nickel and Zinc Use[a], 1960-87

	1960 - 73			1973 - 87		
	$\overline{X}$	t	$\dot{g}$	$\overline{X}$	t	$\dot{g}$
OECD						
Aluminum	1.181	0.047	4.0%	1.343	-0.022	-1.6%
Copper	1.000	-0.010	-1.0%	0.805	-0.014	-1.8%
Lead	0.485	-0.007	-1.4%	0.424	-0.008	-1.9%
Nickel	0.068	0.001	1.5%	0.064	-0.001	-1.7%
Zinc	0.643	-0.002	-0.3%	0.476	-0.013	-2.7%
United States						
Aluminum	1.674	0.065	3.9%	1.667	-0.060	-3.3%
Copper	0.976	-0.005	-0.5%	0.736	-0.015	-2.1%
Lead	0.455	0.001	0.2%	0.444	-0.012	-2.7%
Nickel	0.077	0.000	0.0%	0.056	-0.002	-4.0%
Zinc	0.616	-0.004	-0.6%	0.380	-0.015	-4.1%
EEC[b]						
Aluminum	0.832	0.023	2.8%	1.014	0.002	0.2%
Copper	1.016	-0.022	-2.2%	0.808	-0.013	-1.6%
Lead	0.556	-0.012	-2.2%	0.449	-0.007	-1.5%
Nickel	0.057	0.001	1.8%	0.058	0.000	-0.3%
Zinc	0.636	-0.009	-1.4%	0.480	-0.009	-1.8%
Japan						
Aluminum	1.048	0.097	9.3%	1.557	-0.031	2.0%
Copper	1.205	0.014	1.2%	1.127	-0.022	-2.0%
Lead	0.356	-0.010	-2.8%	0.326	-0.002	-0.7%
Nickel	0.097	0.006	6.2%	0.112	-0.002	-1.8%
Zinc	0.888	0.017	1.9%	0.706	-0.024	-3.3%
United Kingdom						
Aluminum	0.883	-0.003	-0.3%	0.738	-0.027	-3.6%
Copper	1.376	-0.045	-3.3%	0.781	-0.030	-5.0%
Lead	0.699	-0.022	-3.1%	0.555	-0.013	-2.3%
Nickel	0.077	-0.001	-1.3%	0.052	-0.002	-2.9%
Zinc	0.677	-0.015	-2.2%	0.399	-0.019	-4.9%
Federal Republic of Germany						
Aluminum	0.909	0.039	4.3%	1.270	0.011	0.9%
Copper	1.107	-0.020	-1.8%	0.952	-0.013	-1.3%
Lead	0.519	-0.013	-2.5%	0.419	-0.003	-0.8%
Nickel	0.060	0.001	1.7%	0.082	0.001	1.0%
Zinc	0.656	-0.008	-1.2%	0.495	-0.004	-0.7%

Table 2 (continued)

France						
Aluminum	0.780	0.006	0.8%	0.853	0.002	0.3%
Copper	0.783	-0.011	-1.4%	0.612	-0.009	-1.5%
Lead	0.466	-0.015	-3.2%	0.329	-0.008	-2.4%
Nickel	0.064	0.001	1.6%	0.055	-0.001	-1.8%
Zinc	0.553	-0.012	-2.2%	0.430	-0.011	-2.5%

Source: table derived from sources cited at table 1.

[a] Intensity of use is defined here as metal consumption (measured in tons of metal consumed) per unit of GDP (measured in million constant 1980 U.S. dollars).

[b] For the whole period under study, EEC refers to the following countries: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands, United Kingdom.

[c] Annual growth rates are obtained by dividing the slope of the trend line (ι) by the arithmetic mean ($\bar{X}$) for each corresponding period.

already negative or stagnant for all of the OECD countries; in the 1970s and 1980s this tendency merely became more pronounced. The only exception to this trend was Japan, where during the 1960s the intensity-of-use index of copper and of zinc increased by 1-2 percent per year. There, too, in subsequent years, the growth of the index declined and became negative.

- For aluminum and nickel, the situation is rather different. The mean value of the intensity-of-use index of aluminum was higher in 1973-87 than it was during the 1960s, which means that consumption of the light metal continued to increase (decrease) more (less) rapidly than the index of industrial activity. However, the increase was occurring at a declining rate: whereas in 1960-73, aluminum's intensity of use grew by 4 percent or more per year (in the OECD, the United States, Japan, and West Germany), during 1973-1987 it grew by much less. In most countries, the slope of the trend line became negative.
- In the case of nickel, no general tendency can be discerned. The mean value of its intensity-of-use index remained relatively stable for the OECD as a whole and for the EEC: 0.068 and 0.057 for 1960-73; 0.064 and 0.058 for the subsequent period. In the United States, the United Kingdom and France it decreased, while in Japan and West Germany it increased. However, in all countries, the growth rate of nickel's intensity of use declined, in most cases, becoming negative. It remained positive only in West Germany, where it was 1 percent per year.

The above findings lead us to discount any approach that views the atrophy of metals consumption as purely a cyclical phenomenon, which will correct itself with a recovery in economic activity. While there is a direct relationship between metal consumption and the index of industrial activity, that relationship is not stable. The ratio between the two variables has decreased steadily for copper, lead and zinc since 1960. For aluminum and nickel, the decrease in growth of the intensity-of-use index, which occurred in 1973-87 was preceded by fairly steady growth during 1960-73 (4 percent per year for aluminum in OECD countries and 1.5 percent per year for nickel).

If the atrophy of metals consumption is not just a function of the decrease in industrial activity, how can we explain it? In the next section, we will examine the life-cycle hypothesis.

The Life-cycle Theory and Mineral Commodities

G.W. Bain[6] has suggested that, just like consumer products, mineral commodities go through a cycle that consists of four distinct stages: youth, maturity, old age and decline. During the first stage, much research is done on the new ore or metal and information is widely disseminated. Production and consumption rise dramatically, often growing annually by more than 6 percent, faster than the national economy. Adding to the increase in consumption of the metal is a drop in its real price, which is more marked at the beginning than at the end of this stage.

During the second stage, that of maturity, production and consumption of the metal grow more slowly, but steadily, at 2-5 percent per year, about the same rate as economic activity. This stage is characterized by: increased standardization of the production process; better integration of the metal into the process of manufacturing finished or semifabricated products; and a striking stability of the metal's real price.

The third stage, the gerontic stage, is relatively short. In figure 6, which shows the life-cycle of a mineral commodity, it is represented by the highest part of the curve. At this stage, production and consumption of the metal grow less rapidly than industrial activity. This levelling off of growth may result from substitution of the metal by other metals or materials in end-use markets, higher recovery rate for scrap metal, or changes in the design and production of finished products which cause less metal to be used. The behaviour of prices is not always predictable: while relatively stable prices are expected, upsurges can occur, especially near the end of the stage.

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[6] G.W. Bain (1979) "Production Growth Rates as an Index for Amount of Total Resources", *Proceedings of the Eleventh Commonwealth Mining and Metallurgical Congress*, Hong Kong, 1978, IMM, London; G.W. Bain (1980), "World Sources and Resources of Tungsten", *Transactions of the Institution of Mining and Metallurgy*, Section A, vol. 89, April, pp. 58-67.

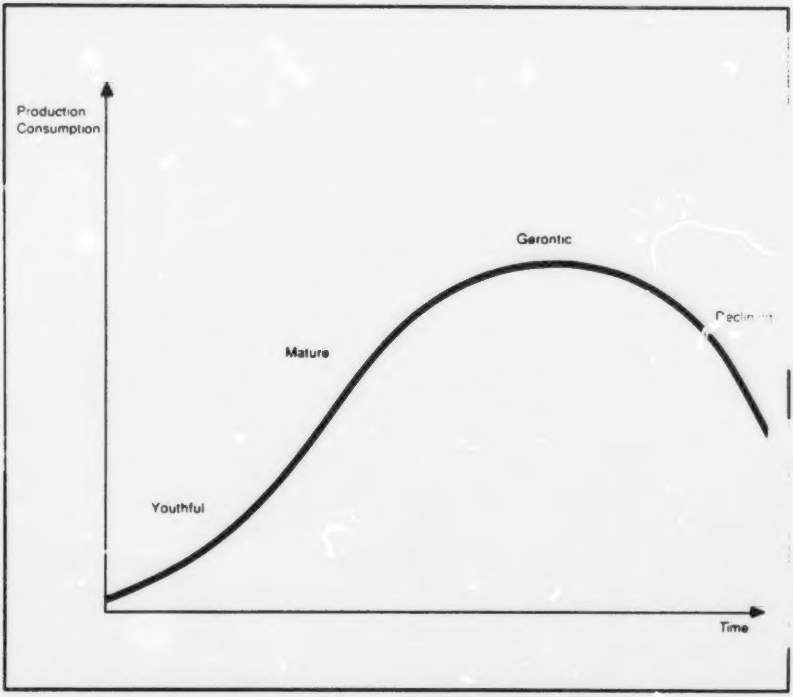

Figure 6. The four stages of a mineral commodity life-cycle

The last stage in the cycle is that of decline in production, resulting from a gradual depletion of high grade deposits, or the refusal of producers to invest in the development of a resource of which the future is uncertain. Demand for the metal shows an absolute decline, as substitution increases and producers fail to find new markets capable of counteracting the effects of substitution. The effect on prices of increasing production costs and declining demand can vary. If the rise in production costs proves more rapid or significant than the decline in demand, prices will tend to increase. In the reverse situation, they may drop slightly.

Although it may be hard to draw an exact line between one stage and another, it is often suggested that aluminum, along with such new metals as niobium, vanadium and gallium, is in the first stage of development, while nickel and copper are in the mature stage. Because so few metals have all of the characteristics mentioned above, it is more difficult to illustrate the last two developmental stages. Lead and zinc are sometimes considered to have reached the gerontic stage, while tin is ranked as a metal in decline, along with some toxic metals that are no longer in demand. How should we assess the metals life-cycle theory? Is it of any use in economic forecasting?

D. Humphreys,[7] who has studied the evolution of world consumption and production and the real prices of eleven ores and metals over more than sixty years, believes that the life-cycle theory is of very limited usefulness. He states that the theory is too general,[8] then points out some specific shortcomings. For example, the life-cycle theory suggests that the development of an ore or metal follows a continuous and predetermined pattern. However, this is really the exception rather than the rule, because a metal's evolution can be affected by such factors as mining policies, fiscal policies and technological developments, which may shorten or lengthen the duration of certain developmental stages or even prevent them from occurring in the expected sequence (for example, aluminum may have gone from the youthful to the gerontic stage, completely bypassing the stage of maturity).[9]

Humphreys' criticism goes further, questioning the very existence of a commodity life-cycle:

> Finally, the question arises as to how far one is justified in talking about *a* commodity life-cycle at all, and whether what one is dealing with is not in fact a series of subcycles superimposed upon each other, each subcycle relating to a specific *application* of the commodity in question. . . Thus, where a material does appear to have followed a cyclical trend, it is likely that this will be a cycle of uses, and one can no more predict the course of such a cycle of uses than one can predict whether an already well-established material might not suddenly develop a whole series of major new applications.[10]

A good illustration of the difficulty of making forecasts by superimposing sub-cycles corresponding to different applications of a metal is the aluminum industry. Knowing that above-ground electric transmission lines have reached the mature stage of development and that soft drink cans in the United States are beginning the gerontic stage tells us very little about future applications of aluminum, such as, for example, the possible penetration of aluminum cans into the food industry or of aluminum shingles in the construction industry.

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[7] D. Humphreys (1982), "A Mineral Commodity Life-cycle? Relationships between Production, Price and Economic Resources", *Resources Policy*, vol. 8, no. 3, September, pp. 215-229.

[8] The evolution of the consumption and production of an ore or metal cannot be understood without reference to the economic context in which that evolution takes place. Thus, the same metal can have reached the third stage of development in an industrial country and only the second stage in a developing country.

[9] In a similar vein, mention is often made of the "leap-frogging" phenomenon. This means that it is possible for developing countries to profit from the experience and the technology of the industrial countries and, for a given level of development, use metals in a less intensive way.

[10] D. Humphreys (1982), *op. cit.*, pp. 226-227.

It appears, then, that each metal (and each application of a given metal) has a life-cycle of its own, which is shaped by the habits and customs of the society in which it is used, the macroeconomic context and the level of development of markets, government policies, the relative success of technological advances aimed at increasing the metal's productivity and slowing down penetration by substitutes, and so on. As the influence of each of these variables on the metals being studied differs, it would be dangerous, to say the least, to try to point to any general tendencies, particularly since the level of development of each of the metals' applications varies. For example, we cannot conclude that lead has reached the stage of decline solely by looking at its use as an additive in gasoline; we must also consider the new uses being developed for it, particularly in the sector of commercial construction.

As it cannot be said that each one of the thousands of applications of the metals under study has gone from youth and maturity to the gerontic stage or into decline, we are led to conclude that the life-cycle theory does not explain the atrophy in metals demand that has occurred over the last fifteen years. We will have to search for other explanations.

Malenbaum's Intensity-of-Use Hypothesis

We mentioned earlier the concept of intensity of use of a metal, which is obtained by dividing the metal's total consumption by an index of industrial activity, either the GDP or the GDI. The evolution of metal consumption is thus expressed in relation to another variable, rather than in absolute terms. As we noted earlier, this measure of a metal's relative consumption does not follow a set pattern. For copper, lead and zinc, the ratio has been constantly decreasing for the past quarter of a century, while for aluminum and nickel, its evolution plotted on a graph makes an inverted "U". How can we explain the evolution of the metals' index of intensity of use and what factors influence it?

These questions have interested a number of economists, in particular W. Malenbaum[11] and economists from the International Iron and Steel Institute

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[11] W. Malenbaum (1973), *Material Requirements in the United States and Abroad in the Year 2000*, a research project prepared for the National Commission on Materials Policy, University of Pennsylvania, Philadelphia; W. Malenbaum (1975), "Law of Demand for Minerals", *Proceedings of the Council of Economics*, 104th Annual Meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers, pp. 146-155; W. Malenbaum (1978), *World Demand for Raw Materials in 1985 and 2000*, McGraw-Hill, New York.

(IISI).[12] Having observed that the intensity-of-use index for most of the metals consumed in the West (except aluminum) has been diminishing during the last few decades, and that in developing countries this does not seem to be the case, Malenbaum suggests that the evolution of the intensity-of-use index (IU_t) is linked to that of economic development, as reflected by a nation's per capita income (GDP/POP). Thus:

$$IU_{t,i} = f\,(GDP_{t,i}/POP_{t,i}) \qquad (1)$$

Of course, Malenbaum recognizes that the exact nature of this relationship must be determined empirically and that it can vary depending either on the metal or the country considered. All the same, he suggests that, in its general form, the relationship expressed by equation (1) can be illustrated by curve A of figure 7. The shape of the curve is based on the hypothesis that metals needs vary over the development cycle.

Thus, metal consumption is very limited in countries with low per capita incomes; their economies are dominated by subsistence agriculture, which requires little machinery. As per capita income rises the importance of the industrial sector grows, as does the part of government revenues devoted to the establishment of an economic infrastructure. All of this makes consumption of metals climb, and thus also their intensity of use. Eventually, as the demand for products like houses, cars, bridges, harbours, hospitals and schools is satisfied and consumers start spending a growing part of their incomes on services, the intensity-of-use index reaches a peak. The peak is also reached as an ever-higher percentage of the GDP is turned over to sophisticated manufacturing activities, which are intensive in human capital and entail limited demand for metals per dollar value added to GDP.

The intensity-of-use index of metals in economies where per capita incomes are even higher will decrease. Malenbaum gives three following reasons for this reversal:

- shifts in the types of final goods and services that world consumers and investors demand directly;
- technological developments that alter the efficiency with which raw materials are discovered, extracted, processed, distributed and utilized in production of final goods;
- substitutions among raw materials inputs consequent upon relative price movements and relative rates of technological development.[13]

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[12] International Iron and Steel Institute, (1972), *Projection 85: World Steel Demand*, Brussels.

[13] W. Malenbaum (1978), *op. cit.* p. 2.

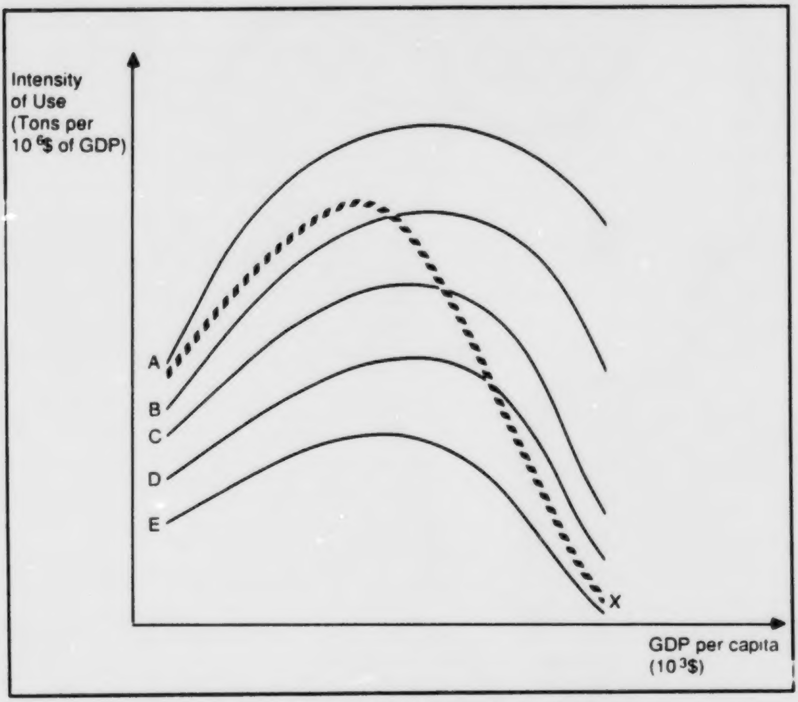

Figure 7. Intensity-of-use hypothesis and the identification problem

We will return later to this suggestion from Malenbaum that the per capita income variable contains within itself the effects of these three forces. For now, let us just note that the relationship expressed in equation (1) can be observed not only at one particular point in time by comparing countries of different levels of development (using cross-section data), but also at different stages of the economic development of any one particular country (using time-series-data).

Malenbaum's hypothesis is interesting because it links changes in metals consumption (per unit of industrial production) to variations in the structural (and not cyclical) variables that determine the level of a country's economic development. The hypothesis is very simple, because it assumes that the influence of all these structural variables is contained within a single variable, that of per capita gross domestic product. Furthermore, the relationship described by equation (1) enables us simply and directly to forecast future consumption of a metal, as all we need to know is forecasts of future population size for a given country and the anticipated value of its GDP, data that are readily available from private or government economic forecasting agencies. No longer are we required to use such cumbersome forecasting techniques as categorizing metal consumption according to the principal end-use markets and, in each case, predicting the effects on consumption of future prices or of the introduction of new technologies.

How should Malenbaum's approach be assessed? In spite of its strengths, which we listed above, his hypothesis also has weaknesses. First, it is doubtful whether the per capita GDP can really capture the influences of variables as disparate as variations in the composition of the GDP (the tertiary sector increasing in importance relative to the secondary, which had previously superseded the primary), technological developments and their effects on production techniques and use of metals; inter-material and intra-metal substitutions; changes in the tastes of consumers and their effects on the design of products and thus on the relative consumption of metals; the effects of government policies on questions related to the environment and occupational health and safety; and so on.

M. Radetzki and J.E. Tilton point out that those who accept the intensity-of-use hypothesis have not demonstrated how all the variables mentioned above are systematically tied to per capita income:

> ..inter-sectoral shifts . . . are presumed to link intensity of use with economic development. Material substitution, new technology, and other factors, however, may also influence intensity of use. While well aware of this possibility, the proponents of the intensity of use hypothesis offer no rationale for assuming the influence of these variables varies over time or among countries in a systematic manner with per capita income. Nor is this surprising, for such a rationale is difficult to construct.
>
> New technology and material substitution generally are discrete events that occur at irregular intervals. Their number, speed of adoption, and ultimate impact on metal use in specific applications vary greatly in response to a variety of factors, including the opportunities they provide for reducing costs and expanding markets. Neither new technology nor material substitution, however, appear to depend primarily on changes in per capita income.[14]

This discussion of one flaw in the hypothesis leads us to another: the relationship between the total consumption of metals/GDP and GDP/POP is not stable. Curve A in figure 7 shows the relationship between these two variables at a particular point in time, let us say 1950. The reason for the curve's inverted "U" shape was given earlier. Even though Malenbaum refers to a whole set of variables to explain the variations in the intensity of use of metals, his choice of GDP/POP as the independent variable favours the view that those variations are due to what is known as the "product composition of income" (PCI), i.e., the mix of goods and services produced by an economy.

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[14] M. Radetzki and J.E. Tilton (1987), "Conceptual and Methodological Issues", paper presented at the *World Metal Demand Workshop* sponsored by Resources for the Future and the Colorado School of Mines, Helsinki, Finland, October 12-13, pp. 22-23.

If we look at curve B, we see the same relationship as before, for the same countries, but at a different point in time, let us say 1975. The shift of the curve downward is explained mainly by technological changes which allow for the production of a given output with fewer and fewer inputs. Thus, at a given level of a country's development, less metal is used in the production of finished or semimanufactured goods because the productivity of metals has increased. This greater productivity, along with inter-material and intra-metal substitutions and the efforts of conservation movements to promote a more rational use of non-renewable resources, serves to modify the "material composition of products" (MCP) and make the curve of the intensity of use of metals shift downward.[15]

As we see, then, the relationship between IU and GDP/POP is not stable. Those who use it as a basis for forecasting long-term demand for metals are, in fact, basing their forecasts on the evolution of a curve X, which is made up of points taken from curves A, B, C, D, etc.[16] This is a good example of what is called by economists an identification error. The proponents of the intensity-of-use hypothesis put primary emphasis on the PCI to explain the variations in the IU index and tend to overlook the impact of technological changes which, in modifying the MCP, increase the productivity of metals. What we need is an approach able to take account simultaneously of both variables.

The third difficulty with Malenbaum's hypothesis is related to the assumption that countries which presently have low per capita incomes will, when they reach the level of development of the industrialized nations, also adopt their pattern of metal consumption. This assumption makes metals producers very happy, for it suggests that the current decline in metals consumption in industrialized countries will be balanced by increased consumption in the presently less developed countries. However, such optimism may be unwarranted, because it is based on the assumption that variations in the IU are caused solely by variations in the PCI. If, as we stated earlier, intensity of use is also influenced by the progressive introduction of technologies that increase the productivity of metals, it can be expected that as developing countries also adopt these technologies, the leapfrog effect will cause them to consume less metal than would otherwise have been expected.

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[15] It should be noted that this is not always the case. The substitution of materials and technological changes can have a beneficial effect on the intensity of use of a metal and push its IU curve upward. This happened in the United States with the development of the aluminum can, which has had a benefical effect on the consumption of aluminum. See Nappi, C. (1987), "Metals Demand and the Food and Beverage Industry: the Case of the United States and a Comparison with Other Industrialized Countries", paper presented at the *World Metal Demand Workshop* sponsored by Resources for the Future and the Colorado School of Mines, Helsinki, Finland, October 12-13.

[16] It should be noted that the instability of the relationship between IU and GDP/POP is not a serious problem if IU is mainly influenced by changes in the PCI and if the effects of new technologies and of substitution among metals and materials are quite marginal. The same holds true if the effects of the variables determining the MCP are constant over time. These two occurrences are not sufficiently common to be considered here.

Still, when we speak of the leapfrog effect, we should exercise caution, as M. N. Lowry[17] points out. Lowry demonstrates that although technological changes have occurred which have reduced the intensity of metal use in less developed countries, most notably by encouraging reductions in the metal content of products, other changes have taken place which have increased the intensity of metal use, for example, by stimulating greater spending on durable goods. Lowry concludes that, when all is said and done, one cannot say with certainty that developing countries today are less metal intensive than most industrialized countries were at a comparable stage of development.

A fourth doubt relating to the intensity-of-use hypothesis was recently expressed by D. Humphreys.[18] The question, why did a decline in the growth of the general demand for metals occur in the early 1970s, is not satisfactorily answered by Malenbaum's claim that it was due to a decrease in the intensity-of-use which takes place when countries reach an advanced stage of development, because, for most of the metals under study, the decline in their intensity of use began a number of decades ago. Humphreys studied the IU index for the whole of the period 1900-85. He found that in all of the industrialized countries, the index for lead (and tin) had been falling since the beginning of the century, while the copper index peaked in the early 1950s (reflecting the rapid growth of electrical uses of copper) and has been diminishing ever since. For zinc, no clear pattern of evolution of the IU index is visible in the first half of the century, but after that, it resembles copper. Only for aluminum did the IU index increase for the whole period; however, since the mid-1970s, it has shown no growth and even decreased slightly. This is Humphreys' conclusion:

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[17] M.N.Lowry (1986), "Assessing Future Metals Demand in Less Developed Countries: Another Look at the Leapfrog Effect", *Materials and Society*, vol. 10, no. 3, pp. 513-527.

[18] D. Humphreys (1987), "Perspectives on Intensity of Use", *Materials and Society*, vol. 11, no. 3, pp. 333-347.

> That the growth in metals consumption slowed dramatically during these years is beyond dispute. However, since economic growth generally also slowed, this proves nothing as regards IU. That the adjustment from a faster to a slower rate of consumption growth resulted in over-investment in the metals industry and, in some cases, a rise in the proportion of consumption accounted for by secondary materials, is also accepted. Indeed, this is probably the heart of the explanation of the industry's problems. But that declining IU, or even an acceleration in the rate of decline, played more than a marginal, aggravating, part in generating these problems seems more doubtful. After all, as the historical record clearly shows, declining IU in industrialized countries is a process of long standing, and encompasses periods of growth and profitability for the metals industry as well as periods of recession.[19]

The four problems with Malenbaum's hypothesis that we have mentioned so far should be enough to make us wary of statements about a law of demand for minerals and metals. There is yet another difficulty, which relates to problems of an empirical nature. These measurement problems, presented and evaluated in the appendix A, apply not only to Malenbaum's hypothesis and its empirical extensions, but to all econometric studies of demand which use data on metals consumption. This is not necessarily true of the other problems we have mentioned: specification error (in assuming that variations in GDP/POP capture the influence of the MCP variable); instability of the relationship between C/GDP and GDP/POP; identification error, and the failure to take account of the leapfrog effect.

We have seen that Malenbaum's hypothesis has many flaws; but it does have the merit of pointing out that the slackening or atrophy in metals consumption may be not just a passing or cyclical phenomenon, but rather, a reflection of fundamental structural changes in the economic system. If the effects of those changes cannot be captured by Malenbaum's hypothesis, what other methods or techniques are available and what are their advantages and disadvantages? In the next section, we will briefly survey the existing methods and examine in detail the technique of intensity-of-use (as distinguished from the hypothesis of intensity-of-use).

Structural Changes and the Intensity-of-Use Technique

If we accept that the slowdown or atrophy in the growth of metals demand is owing to changes in the structure of the economy, we must determine how to qualify and quantify those changes. In other words, what are the elements of a structural change and how can we capture their effects? Several approaches to this problem have been explored by economists. One approach is to use econometric methods to estimate a function of demand in which variations in the total consumption of a metal are explained by variations in a set of indepen-

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19 D. Humphreys (1987), *op. cit.*, pp. 335-336.

dent variables, such as the price of the metal, the level of production of finished or semimanufactured goods that use that input in various degrees, the prices of different substitute metals or materials, technological changes and other variables, which capture the effects of economic policies and changes in the market's institutions. Demand functions can thus be used to gauge the impact on a metal's consumption of technological changes or of changes in pressure from the substitutes. It should be noted that to account for the effects of technologies, a time trend or a Gompertz function is often used, while competition among substitutes is considered to be accounted for by a price variable (very few studies have recognized that substitution can occur only when the price of an alternative material has attained a certain threshold of reaction).[20]

These demand functions which accord a major role in the allocation of resources to prices, are certainly interesting, but the approach has attracted much criticism. Some have criticized it for its failure to show the dynamics by which substitution is carried out; others have expressed doubt about the preponderant role assigned to relative prices, as compared to technology, in metals demand.[21] Finally, the bases upon which demand is estimated (stability of the relationship, reversibility, continuity) have been put into question, particularly as applied to metals.[22]

A second approach consists of specifying and estimating a production function (or the costs function associated with it) in cases where "structural change" refers to an inter-material or intra-metal substitution. This interest in substitution is explained by short- and long-term considerations which have been summed up as follows by M.E. Slade:

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[20] An interesting way of reformulating the demand for metals has recently been proposed by T.J. Considine. Beginning with the idea that metals, like energy, are used with capital equipment for the production of finished or semimanufactured goods, Considine suggests that the operation of machinery implies consumption of raw materials in quantities that are determined by the level of output and the technical characteristics of the equipment, T.J. Considine (1987), "Understanding Trends in Metal Demand," *Materials and Society*, vol. 11, no. 3, pp 359-361. The interested reader is also referred to the two following demand studies: M. Hazilla and R.J. Kapp (1984), "A Factor Demand Model for Strategic Nonfuel Minerals in the Primary Metals Sector", *Land Economics*, vol. 60, no. 4, November, pp. 328-339; and Jack Faucett Associates (1986), *Changes in Worldwide Demand for Metal Minerals*, Final Report Submitted to the Bureau of Mines, Washington, D.C., August, 165 pages.

[21] R.T. Newcomb (1976), "Mineral Industry Demands and General Market Equilibrium", *Economics of the Mineral Industries*, Third Edition, AIME, New York, pp. 271-316.

[22] J.E. Tilton (ed.) (1983), *Material Substitution: Lessons from Tin-Using Industries*, Resources for the Future, Washington, pp. 7-8.

> Interest in the possibility of substituting materials for other inputs to the production process is motivated by several concerns. Perhaps the most important ones are those pertaining to short-run supply disruptions and to long-run exhaustion of depletable natural resources. In the short run, most industrial nations . . . need to know what substitutes exist for commodities that are temporarily in short supply and how long it takes to substitute an available commodity for one whose price has increased or that cannot be obtained. In the long run, as the stocks of natural resources are depleted, it becomes essential to assess the possibility of substituting reproducible inputs such as capital and labour for scarce inputs such as non-renewable energy and minerals. Econometric models have been constructed and estimated to help us to understand the process of substitution and to aid in assessing the importance of both these issues.[23]

Our interest here is primarily in long-term materials substitution. If we accept that metals use is linked to the stock of capital equipment presently in use, we can say that demand for metals will be affected by the rate at which, in the long run, new generations of metal-consuming capital stock replace the old and therefore the extent to which this process alters the structural parameters. Many analyses of metals demand have attempted to address the issue of complementarity or substitutability of metals with capital or labour as inputs in the production function,[24] but these studies have been much criticized. Among the criticisms levelled against them is the fact that the production functions they use are not in line with the hypotheses of the separability of metals and non-metals inputs, or of homotheticity and duality.

A third approach is to use input-output analysis, studying the evolution over time of direct and total coefficients. Direct coefficients indicate the proportion of each dollar of the output of an industry that is spent on a given commodity input; the total coefficient tells us the proportion of each dollar of industry final demand that is spent on a metal both directly and indirectly. A variation in direct coefficients (due, for example, to a decrease in the use of aluminum per dollar of production of metal cans) will indicate and measure the substitution taking place among material inputs as well as the effects of a material-saving technical change.[25] This method of analysis entails many difficulties. Input-output tables are sometimes unavailable for the countries being studied, or may be much delayed. Because they are not homogeneous, international comparisons are difficult to make. As J.G. Myers has pointed out, a variation in direct coefficients over time may indicate things other than those mentioned above, such as: a change in the product mix of industries which leads to different input requirements; a reorganization of plants which may lead to more or less processing within an industry; or a change in the product or industrial classification system.

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[23] M.E. Slade (1981), "Recent Advances in Econometric Estimation of Materials Substitution", *Resources Policy*, vol. 7, no. 2, June, p. 103.

[24] A survey of these studies can be found in the following two works: M.E. Slade (1981), *op. cit.*, pp. 103-109; E.R. Berndt and B.C. Field (eds.) (1981), *Modeling and Measuring Natural Resource Substitution*, MIT Press, Cambridge, Massachusetts, chap. 1.

[25] For an example of the application of this method of analysis to the problem under study, see J.G. Myers (1986), "Testing for Structural Change in Metals Use", *Materials and Society*, vol. 10, no. 3, pp. 271-284.

The last approach we will consider claims to be not so much a method of evaluating the structural elements responsible for the slackening in the long-term metals demand, as a way of structuring our thinking on the subject. It suggests the variables that should be analyzed, rather than providing an exact technique for doing so. This approach, which was popularized by J.E. Tilton[26] and expanded by M.C. Roberts,[27] can be summed up as follows.

The demand for a metal over a year t (D_t) depends essentially on two variables: the quantity of metal used directly or indirectly per unit of output for each final good i produced by an economy in year t (a_{it}) and the level of production measured in physical quantities of the ith good in year t (P_{it}). If in the course of year t the economic system produces a number n_t of final goods, we can say that

$$D_t = \mathop{\varepsilon}\limits_{i=1}^{n_t} a_{it} \cdot P_{it} \qquad (2)$$

If we define b_{it} as being the share of the production of the ith good (P_{it}) in the national revenue (Y_t) during the year t:

$$b_{it} = P_{it} / Y_t \qquad (3)$$

and if we substitute the value of P_{it} (shown by equation 3) in equation (2), we get

$$D_t = Y_t \mathop{\varepsilon}\limits_{i=1}^{n_t} a_{it} \cdot b_{it} \qquad (4)$$

This identity suggests that demand over time for a metal is the result of three forces: the level of economic activity of the region for which we are measuring the demand (Y_t), the material composition of products (a_{it}) and the product composition of income (b_{it}).

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[26] J.E. Tilton (1986), "Mineral Investment in Developing Countries in the Wake of Slower Growth in World Metal Demand", unpublished paper presented at a conference on Mining Ventures in Developing Countries, AIW-Institute for Foreign and International Trade Law, University of Frankfurt, Frankfurt; see also M. Radetzki and J.E. Tilton (1987), *op. cit.*, pp. 17-20.

[27] M.C. Roberts (1987), "The Consumption of Metals and International Trade", *Materials and Society*, vol. 11, no. 3, pp. 391-406.

If we want to express the demand for a metal in relative terms, that is, in relation to an index of economic activity in a region, then the intensity-of-use (IU) of the metal becomes a function of the last two forces mentioned:

$$IU_t = D_t / Y_t = \sum_{i=1}^{n_t} a_{it} \cdot b_{it} \qquad (5)$$

or

$$D_t = IU_t \, . \, Y_t \qquad (6)$$

This very simple technique, which dissects the determinants of a metal's intensity-of-use index, suggests that if we want to understand the atrophy in the demand for metals, or the slowdown in its rate of growth over the last fifteen years, we must follow the steps outlined in figure 8 (the figure includes the developments suggested by Roberts, which we will present in the appendix B).

It should be noted that the procedure does not end with equation (5) or (6); we also need to understand why the value of b_{it} changes over time. Is it solely because of the economy's inter-sectoral shifts, caused by the phenomenal growth of the service sector (with a low intensity in metals) relative to the primary and secondary sectors? Or do we also need to consider the effects of intra-sectoral shifts, of manufactured products less intensive in metals increasing their part of the secondary sector *vis-à-vis* more traditional products? How do we explain the variations over time of a_{it}? What part of this variation is due to substitution among metals (we must distinguish between intra-metal substitution and inter-material substitution: in the latter case, metals are replaced by plastics and other polymers, composite products and, in certain end-use markets, even by industrial ceramics)? What percentage of the variation of a_{it} results from the use of resource-saving new technologies?

The intensity-of-use technique has the merit of pointing to the problems and posing the right questions, even if it does not provide the answers. It falls somewhere between just stating the problem (the atrophy of the demand for metals) and determining the influence of different independent variables, one of which is certainly relative prices. Since the dynamics by which relative prices affect metals substitution and the use of metal-saving technologies are far from being clear, we must content ourselves with this second-best, which, although not focusing on the final determinants of metals demand, succeeds in capturing their effects.

This quality of the intensity-of-use technique has often been misunderstood. Critics of the procedure suggested by Tilton have called it "a mechanical, ad

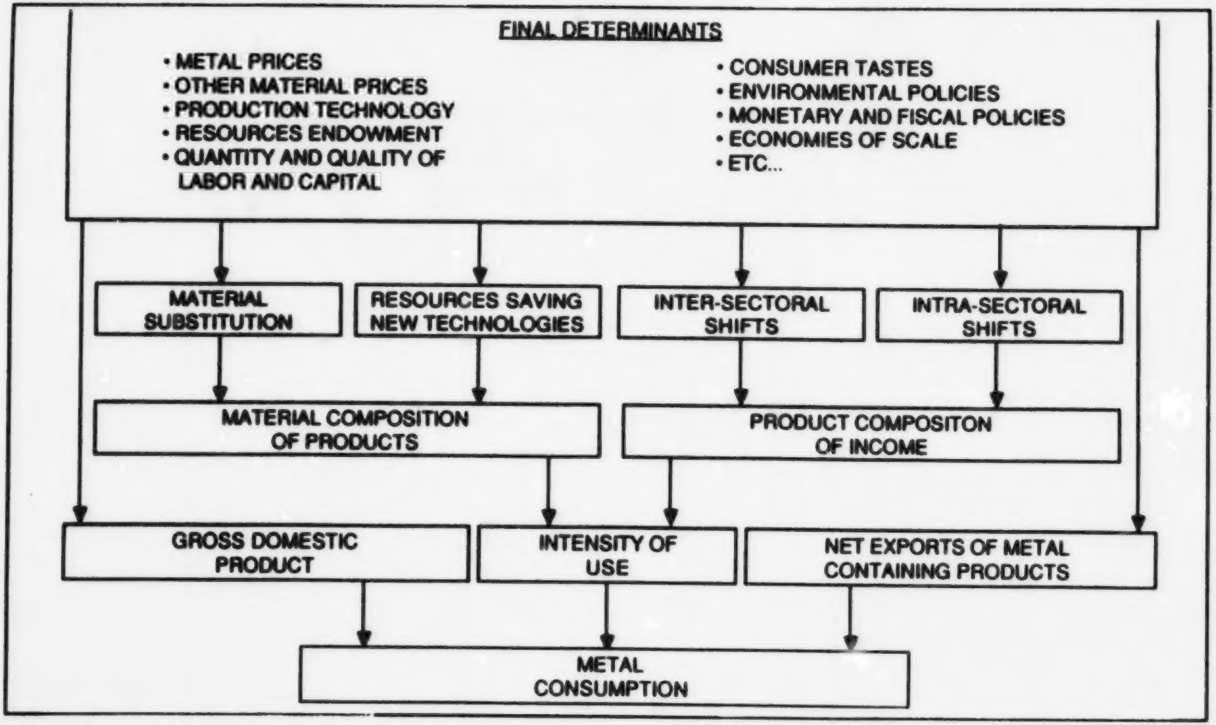
FINAL DETERMINANTS
• METAL PRICES
• OTHER MATERIAL PRICES
• PRODUCTION TECHNOLOGY
• RESOURCES ENDOWMENT
• QUANTITY AND QUALITY OF LABOR AND CAPITAL
• CONSUMER TASTES
• ENVIRONMENTAL POLICIES
• MONETARY AND FISCAL POLICIES
• ECONOMIES OF SCALE
• ETC...
MATERIAL SUBSTITUTION
RESOURCES SAVING NEW TECHNOLOGIES
INTER-SECTORAL SHIFTS
INTRA-SECTORAL SHIFTS
MATERIAL COMPOSITION OF PRODUCTS
PRODUCT COMPOSITON OF INCOME
GROSS DOMESTIC PRODUCT
INTENSITY OF USE
NET EXPORTS OF METAL CONTAINING PRODUCTS
METAL CONSUMPTION

Figure 8. Intensity -of-use technique

hoc, manipulation of the intensity-of-use tautology"[28] that tries to diminish the role which should be accorded to market forces in explaining the decline in the growth of metals demand. Here is how Tilton and Radetzki respond:

> It is important to stress, however, that GDP, the material composition of products, and the product composition of income are not the final determinants of metal demand, but instead simply reflect the latter's influence. Ultimately, metal demand is determined by consumer tastes, production technology, material prices, and government policies, including monetary and fiscal policies. So a full understanding of metal demand trends requires looking behind GDP, the material composition of products, and the product composition of income, and the factors that cause these variables, and in the process metal demand, to change over time. The later steps in the intensity-of-use technique are supposed to do just that, though in practice this is often difficult to do in any rigorous manner and a number of analyses have stopped short of these steps.[29]

Tilton's procedure is interesting, but it fails to explicitly take account of the role in metals demand of international trade. Roberts[30] corrects this omission by proposing an extension, which is presented in the appendix B. His specification suggests that variations in the total consumption of a metal can be explained by the level of industrial activity and the net exports of metal containing manufactured products. These two variables will have a greater or lesser effect on the total consumption of a metal, depending on the value of two ratios: the product composition of income (b_{it}) and the material composition of products (a_{it}).

How should we assess the Tilton-Roberts technique? It makes possible the reconciliation of two schools of thought, that which emphasizes the importance of the relationship between income and metals consumption and that which lays stress on technological change and material substitution to explain recent consumption trends. With this technique, we avoid the specification error made by Malenbaum, who thought he could capture in a single variable (GDP/POP) the influence of the different variables suggested by the two schools of thought. The technique also steers clear of the identification error that results from the instability of the relationship between C/GDP and GDP/POP. By introducing net exports of metal-containing products as an independent variable, it lessens the impact of the measurement problem caused by the difference between the reported consumption of metals and their overall absorption.

In our view, however, the main advantage of the Tilton-Roberts technique is that it constitutes a second-best solution, when the effects of the final determinants of metal consumption cannot be gauged because of the failure of the quantity-price relationship to abide by the hypotheses of stability, reversibility and continuity. This does not mean that the technique presents no difficulties. Several of the measurement problems, presented in appendix A, with regard to Malenbaum's hypothesis (the possible need to adjust metal consumption measured in tonnes by an index of quality or to measure consumption in terms of monetary value; the failure to exclude net additions to inventories; unequal accounting for secondary metals, etc.), as well as the problem raised by Humphreys of the tendentious lowering of the intensity-of-use index, apply to a large extent to this technique as well. As we stated earlier, these difficulties (in particular the measurement problems) are present in the vast majority of studies dealing with metals consumption; once noted and taken into consideration, they are best simply lived with. Another shortcoming of the technique is that while it links the total consumption of a metal to three well-defined variables, it does not explain the exact form of this relationship either at the aggregate level or at the level of the metal's end-use markets.

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[28] T.J. Considine (1987), *op. cit.*, pp. 349-350. See also T.J. Considine (1986), "Atrophy in Metal Demand: Truth or Consequences?", *Materials and Society*, vol. 10, no. 3, pp. 529-530.

[29] M. Radetzki and J.E. Tilton (1987), *op. cit.*, p. 28.

[30] M.C. Roberts (1987), *op. cit.*, pp. 391-406.

In this section, we have tried to assess some of the explanations that have been put forward for the atrophy in demand for the principal metals, or the net slowdown in the growth of demand over the last fifteen years. Obviously, our survey is not complete. For example, we did not present Roberts' hypothesis[31] postulating a saturation point for the demand for physical goods, nor the theory of R. Adams,[32] who believes that the real problem lies with the increasingly cyclical nature of the world economy and the impact of this on the sectors that use metals.[33]

Nevertheless, it has become clear that variations in metals consumption cannot be explained entirely by changes in the index of industrial activity, but that the structure of the economy must be taken into account. Although the structural causes of variations in consumption are numerous, they can be grouped into two general categories: changes in the product composition of income (which occur as the service sector increases its share *vis-à-vis* the primary and secondary sectors, and as within the secondary sector there is an increase in the importance of products which are intensive in technology and the fabrication of which requires fewer and fewer mineral resources) and changes in the material composition of products (as a result of inter-material or intra-metal substitution, and of the progressive adoption of resource-saving new technologies). In addition to the cyclical and structural variables we have mentioned, a third variable must sometimes be added to take account of the effects on the total absorption of metals of significant deficits (as in Australia, Canada, Mexico, or perhaps the United Kingdom) or surpluses (as in Italy, Japan and the Federal Republic of Germany) in international trade of metal-containing manufactured products.

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[31] M.C. Roberts (1985), "Theory and Practice of the Intensity of Use Method of Mineral Consumption Forecasting", unpublished Ph. D. dissertation, University of Arizona.

[32] R. Adams (1985), "The Long-Term Issues Affecting the U.S. Mineral Industry", *Minerals and Materials*, Bureau of Mines, June/July, pp. 41-45.

[33] For a good, brief review of the literature, see G.A. Campbell (1986), "Reflections on the Derived Demand for Metals", *Materials and Society*, vol. 10, no. 3, pp. 345-349.

In the next section, we will first try to determine which part of the observed variations in metals consumption results from structural changes and which from cyclical variations in the index of industrial activity. We will then examine metals consumption within a number of end-use markets, in order to determine the relative importance of the two structural variables, a_{it} and b_{it}. Finally, we will adjust our findings to take account of the net exports of metal-containing manufactured products by the countries being studied.

4. Main Determinants of Atrophy in Metals Demand

Relative Importance of GDP and Intensity of Use

If we disregard for now the effect of net exports of manufactured products on the total absorption of metals, we see from equation (15) in the appendix B that metals use is simply equivalent to the product of the variables representing industrial activity (Y_t) and the index of intensity of use (IU_t). We can thus assume that the growth rate of a metal's consumption will largely depend on the growth rates of those two variables. Indeed, if we accept equation (6), we can show that the growth rate of D_t is equal to the sum of the growth rates of Y_t and IU_t plus a certain margin of error to account for measurement error.

We will first try to determine the relative importance of the two abovementioned variables. Table 3 shows the growth rates of D_t, Y_t and IU_t for 1960-73 and 1973-87 for the metals and regions under study, as well as what the growth rate of the consumption of each metal would have been during 1973-87 if the intensity of use (or the index of industrial activity) had increased during that period at the same rate as during 1960-73.

If we consider aluminum, we find that in OECD countries the atrophy in demand results mainly from structural changes, the effects of which are expressed by the evolution of aluminum's index of intensity of use. Had the growth rate of IU_t not fallen from 4 percent to -1.6 percent per year between the two periods under study, consumption of aluminum would have continued to increase by 6.5 percent annually during 1973-87, rather than at the observed rate of 0.9 percent. If we assume the growth rate of the cyclical variable (Y_t) to be stable, the projected growth rate of aluminum consumption proves less attractive (3.2 percent per year instead of 0.9).

The conclusion that greater importance should be accorded to the evolution of IU_t than to that of Y_t in explaining the slowdown in the growth of consumption applies not only to aluminum, but also, to a lesser extent, to nickel and zinc. Had the index of the intensity of use of the last two metals not lowered its growth (from 1.5 percent per year to -1.7 percent in the case of nickel and from -0.3 percent to -2.7 percent in the case of zinc), their consumption during 1973-87 would have grown annually by 4 percent (nickel) and 2.2 percent (zinc), rather than at the actual rates of 0.8 percent and -0.2 percent respectively. Assuming a stable rate of growth of the GDP gives a lower growth in the consumption of the two metals.

Table 3:
Percentage Growth in Metal Consumption, Intensity of Use and Gross Domestic Product 1960-73 and 1973-87

Area Metal and Time Period	Observed			Projected Metal Consumption in 1973-87 Period Assuming 1960-73 Growth in	
	Metal Consumption (percent)	Gross Domestic Product (percent)	Intensity of Use (percent)	Intensity of Use (percent)	GDP (percent)
OECD					
Aluminum					
1960-73	8.6	4.8	4.0		
1973-87	0.9	2.5	-1.6	6.5	3.2
Copper					
1960-73	3.8	4.8	-1.0		
1973-87	0.7	2.5	-1.8	1.5	3.0
Lead					
1960-73	3.4	4.8	-1.4		
1973-87	0.5	2.5	-1.9	1.1	2.9
Nickel					
1960-73	6.4	4.8	1.5		
1973-87	0.8	2.5	-1.7	4.0	3.1
Zinc					
1960-73	4.3	4.8	-0.3		
1973-87	-0.2	2.5	-2.7	2.2	2.1
United States					
Aluminum					
1960-73	7.5	3.9	3.9		
1973-87	-0.8	2.5	-3.3	6.4	0.3
Copper					
1960-73	3.3	3.9	-0.5		
1973-87	0.5	2.5	-2.1	2.0	1.8
Lead					
1960-73	4.0	3.9	0.2		
1973-87	-0.3	2.5	-2.7	2.7	1.2
Nickel					
1960-73	3.3	3.9	0.0		
1973-87	-1.4	2.5	-4.0	2.5	-0.1
Zinc					
1960-73	3.1	3.9	-0.6		
1973-87	-1.4	2.5	-4.1	1.9	-0.2

Table 3 (continued)

EEC[a]					
Aluminum					
1960-73	7.1	4.4	2.8		
1973-87	2.0	1.8	0.2	4.6	4.2
Copper					
1960-73	2.3	4.4	-2.2		
1973-87	0.2	1.8	-1.6	-0.4	2.8
Lead					
1960-73	2.3	4.4	-2.2		
1973-87	0.3	1.8	-1.5	-0.4	2.9
Nickel					
1960-73	5.5	4.4	1.8		
1973-87	1.6	1.8	-0.3	3.6	4.1
Zinc					
1960-73	3.1	4.4	-1.4		
1973-87	0.0	1.8	-1.8	0.4	2.6
Japan					
Aluminum					
1960-73	16.9	8.9	9.3		
1973-87	1.9	3.9	-2.0	13.2	6.9
Copper					
1960-73	10.2	8.9	1.2		
1973-87	1.9	3.9	-2.0	5.1	6.9
Lead					
1960-73	6.4	8.9	-2.8		
1973-87	3.0	3.9	-0.7	1.1	8.2
Nickel					
1960-73	14.4	8.9	6.2		
1973-87	2.3	3.9	-1.8	10.1	7.1
Zinc					
1960-73	10.4	8.9	1.9		
1973-87	0.6	3.9	-3.3	5.8	5.6
United Kingdom					
Aluminum					
1960-73	2.6	2.9	-0.3		
1973-87	-2.2	1.4	-3.6	1.1	-0.7
Copper					
1960-73	-0.4	2.9	-3.3		
1973-87	-3.7	1.4	-5.0	-1.7	-2.1
Lead					
1960-73	-0.4	2.9	-3.1		
1973-87	-0.9	1.4	-2.3	-1.7	0.6

Table 3 (continued)

Nickel					
1960-73	1.2	2.9	-1.3		
1973-87	-1.4	1.4	-2.9	0.1	0.0
Zinc					
1960-73	0.7	2.9	-2.2		
1973-87	-3.5	1.4	-4.9	-0.8	-2.0
Federal Republic of Germany					
Aluminum					
1960-73	8.6	4.4	4.3		
1973-87	2.8	1.9	0.9	6.2	3.5
Copper					
1960-73	2.8	4.4	-1.8		
1973-87	0.6	1.9	-1.3	0.1	3.1
Lead					
1960-73	1.8	4.4	-2.5		
1973-87	1.1	1.9	-0.8	-0.6	3.6
Nickel					
1960-73	6.7	4.4	1.7		
1973-87	2.9	1.9	1.0	3.6	5.4
Zinc					
1960-73	3.3	4.4	-1.2		
1973-87	1.3	1.9	-0.7	0.7	3.7
France					
Aluminum					
1960-73	6.1	5.3	0.8		
1973-87	2.2	2.0	0.3	2.8	5.6
Copper					
1960-73	4.0	5.3	-1.4		
1973-87	0.6	2.0	-1.5	0.6	3.8
Lead					
1960-73	2.3	5.3	-3.2		
1973-87	-0.3	2.0	-2.4	-1.2	2.9
Nickel					
1960-73	6.2	5.3	1.6		
1973-87	0.2	2.0	-1.8	3.6	3.5
Zinc					
1960-73	3.4	5.3	-2.2		
1973-87	-0.5	2.0	-2.5	-0.2	2.8

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[a] EEC: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands, United Kingdom

An entirely different pattern is shown by copper and lead. Although their intensity of use has also decreased, they have not done badly considering the generally poor performance of industrial activity. Had the GDP grown in 1973-87 at the same rate as during the previous period, copper and lead consumption would have increased by around 3 percent per year, rather than at the anemic actual rates of 0.7 percent and 0.5 percent respectively.

The trends we have been describing apply to the OECD as a whole; for individual members, adjustments have to be made. In the United States, for example, the atrophy of metals consumption is attributable more to structural changes than to the economic recession. During 1973-87, the U.S. index of intensity of use of aluminum showed a negative growth of -3.3 percent per year, a very clear decline compared to 1960-73 (3.9 percent per year). Similarly, for nickel and zinc, the intensity-of-use index grew by -4 percent per year during 1973-87, while earlier it had been stagnant in the case of nickel and slightly negative in the case of zinc. As the slowdown in the growth of the intensity of use of the five metals in the U.S. is greater than that of the GDP for the two periods, we can conclude that had the structural changes measured by the evolution of IU_t not occurred, consumption of most metals would have grown by a positive number, rather than by the actual rates of 0 to -2 percent per year.

In the EEC, the situation is almost the reverse of the United States. Apart from the consumption of aluminum, where structural factors appear more significant than the cyclical variable, the European slowdown in the growth of metals consumption results essentially from the slowdown in the growth of industrial activity. While the GDP of the EEC increased by 4.4 percent per year during 1960-73, in the period that followed it grew by only 1.8 percent per year, thus showing a much greater decrease than the metals' index of intensity of use. Interestingly, the intensity-of-use index of copper and lead has slowed down its decline. Whereas during the 1960s and early 1970s it decreased by 2.2 percent per year, the decline has slackened to 1.6 percent annually for copper and 1.5 percent for lead.

The general tendencies of the EEC also prove true for its main member countries. Apart from a few exceptions,[34] variations in the material composition of products and in the product composition of income (which jointly determine the value of IU_t) appear less significant for metals consumption in these countries than variations in the economic cycle. Thus, apart from a few exceptions, European metals consumption would have shown more of an increase had the growth rate of the GDP not varied than had the IU_t remained stable.

In Japan, as in the OECD, a major decline occurred in the growth of the intensity of use of aluminum (9.3 percent per year during 1960-73, -2 percent per year during 1973-87), nickel (6.2 percent and -1.8 percent) and zinc (1.9 percent and -3.3 percent). Were it not for those slumps, consumption of the three metals would have grown five to six times faster than it has. On the other hand, the decline in the growth of copper and lead consumption is due primarily to a poorer economic performance, as measured by the evolution of the GDP. Thus, for copper and lead, the decline in the growth of the Japanese GDP (from 8.9 percent to 3.9 percent per year) has been more significant than the decline in the growth of the metals' intensity of use.

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[34] These exceptions are the consumption of aluminum in the Federal Republic of Germany, of aluminum, nickel and zinc in the United Kingdom and of nickel in France.

Our brief analysis shows that changes in structural factors are as important as changes in the performance of industrial activity in explaining the atrophy of demand for the principal metals or the slowdown in the growth of their consumption. In fact, for the OECD as a whole, the United States and Japan, structural variables are more significant than those relating to economic activity; only in the EEC do variations in the economic cycle better explain the decline in metals demand than variations in structural variables.

What of the variations that occur in the GDP and the metals' intensity-of-use index? Variations in the GDP can be explained by a whole set of variables, the relative importance of which has been assessed in other studies.[35] With regard to the variables determining metals' intensity-of-use, the situation is quite different, for we do not know the relative importance of variations in the material composition of products (a_{it}) as compared to those in the product composition of income (b_{it}). Furthermore, there are no detailed studies which make it possible to quantify the respective influences of the variables determining the variations of a_{it} and b_{it}.

We will not attempt such a quantification here because, while a statistical estimation of equation (5) for a given country over time or for a number of countries simultaneously is possible,[36] it would require considerable time and would, in the end, give an overly-aggregate view of the situation. Instead, we will try in the next section to document the relationship, that is, to show in relation to the metals' principal end-use markets the importance of such factors as substitution by other metals or materials, the progressive adoption of resource-saving technologies, and intersectoral or intrasectoral shifts in an economy's national income. What this tells us about the relative influence of a_{it} and b_{it} on IU_t will, perhaps, be less precise, but, we hope, much more useful and pertinent to our needs. As U.S. statistical data is so readily available, we will concentrate on U.S. consumption and production habits; in any case, as we already stated, that country is the most important market for Canadian metals exports.

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[35] A. Maddison (1987), "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment", *Journal of Economic Literature*, vol. 25, June, pp. 649-698.

[36] Such a quantification has been attempted by M.C. Roberts (1987), *op. cit.*, pp. 391-406.

Metals Demand and Structural Changes

Aluminum

Aluminum is a relatively young metal, for its industrial production did not begin until the turn of this century. The metal's technical characteristics[37] and an aggressive marketing policy meant that for many years its consumption grew much faster than did the GDP.[38]

Table 4 shows the relative importance at different times of aluminum's principal end-use markets. We see that now about 30 percent of American domesticshipments of aluminum go to the containers and packaging sector, a much larger proportion than at the beginning of the 1960s. Two other principal outlets for American aluminum sales are the building & construction and the transportation markets, each of which take about 20 percent. The market share of transportation has remained very stable over the years, while the share of the construction sector has shown a small but steady decline, with shipments to that sector increasing slightly less rapidly than total domestic aluminum sales. In 1987, the three sectors together accounted for more than 70 percent of total American domestic aluminum sales, compared to just below 60 percent in the previous years.

The electrical products sector is no longer as important as it was in the late 1960s, when aluminum cables were replacing copper wire in the transmission of high-voltage electricity. Once that process of change was almost completed, aluminum sales fell back to reflect the index of industrial activity. The relative share of the two other end-use markets (consumer durables and machinery equipment) in the total domestic sales of American aluminum has not ceased to diminish over the last twenty-five years.

In other industrialized countries, the end-use market consumption of aluminum does not follow the American pattern. In West Germany, France, Italy and Japan, the transportation sector is the most important outlet, while in the United Kingdom, the construction sector is primary. Let us note that with the exception of the United States and the United Kingdom, the share of aluminum sales held by the containers and packaging sector rarely exceeds 10 percent, while only in France does the electrical products industry absorb more than 10 percent. The market shares described are not always stable. For example, in Japan and

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[37] These characteristics are: an excellent resistance to atmospheric corrosion; great ductility (after lamination, aluminum lengthens by 30 percent to 40 percent); a lower density than copper; and electric conductivity 60 percent to 65 percent that of copper, depending on the degree of purity of the metal.

[38] Canada is in second place among producing nations, having 11 percent of production by countries with a market economy, behind the United States (30 percent) and followed by Australia (7 percent), the Federal Republic of Germany (6 percent) and Norway (6 percent).

Table 4:
Aluminum Net Shipments by Major Market: USA Various Years (percent)

Major Market	1960	1965	1970	1975	1980	1987
Building & construction	29.6	25.4	25.1	24.6	21.8	21.1
Transportation	20.8	23.7	17.3	18.7	18.6	20.7
Consumer durables	12.5	11.4	10.4	8.3	7.3	8.4
Electrical	12.8	14.3	15.2	13.3	11.6	9.2
Machinery & equipment	8.1	7.6	6.8	7.1	6.9	5.9
Containers & packaging	7.8	8.7	16.4	22.2	27.8	30.1
Other	8.4	8.9	8.8	5.8	6.0	4.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: Aluminum Association, *Aluminum Statistical Review*, Washington, various issues.

West Germany, the share of the construction sector is declining, while that of the transportation sector is increasing. In the United Kingdom, both of those sectors have been overtaken by containers and packaging. In Italy and France, market shares have remained quite stable; the only exception seems to be the French transportation sector, the importance of which for sales of aluminum has been diminishing steadily for several years.

Such shifts and changes in market shares are a normal occurrence. Because of changes in relative prices or in consumer tastes, substitution, or a lack of synchronization in the introduction of new technologies in end-use markets, sectoral sales and total sales of aluminum grow at varying rates. We stated earlier that for aluminum, structural factors outweigh cyclical ones in explaining variations in total consumption. How can these structural changes be qualified? Have inter-material or intra-metal substitution affected aluminum demand more than the use of metal saving technologies for the production of finished or semimanufactured goods? Or is atrophy of aluminum demand explained mainly by the growing importance within the GDP of the service sector, or by the fact that within the secondary sector the market share held by miniaturized electronic products is increasing to the detriment of products more intensive in aluminum?

No theoretical model exists to allow us to answer these questions precisely and thus single out one structural factor, nor any empirical method to enable us to distinguish among them. If we cannot solve a problem, we can choose instead to document it. Thus in the next few pages we will examine each of the principal end-use markets of aluminum in order to determine how a_{it} and b_{it} are constituted and how their variations are explained.

CONTAINERS AND PACKAGING

The atrophy of aluminum consumption can hardly be attributed to the containers and packaging sector, at least in the United States. In 1987, this end-use market absorbed about 30 percent of total American aluminum shipments, compared to under 8 percent in 1960. Shipments to this sector increased during that time from 145,000 tonnes to more than 2.1 million tonnes, showing an annual growth of 47.8 percent.

A significant share of the aluminum consumed by this sector goes to the beverage industry. Figures 9 and 10 show the stiff competition that exists among the different materials used for the production of containers for the beer and soft drink industry. We can see that in the beer industry, the market share held by the aluminum can has constantly increased since 1963, the year of its introduction. The aluminum can's competitors, refillable and non-refillable glass bottles, and, particularly, steel cans, have fared less well. In 1986, 62 percent of all the beer sold in the United States was packaged in aluminum cans. The aluminum can's share of the canned beer market is even more impressive; since the beginning of the 1980s, aluminum cans have completely dominated this market, with a share of 99 percent.

In the soft drink containers market, the aluminum can has performed less impressively. Figure 10 shows that although its market share has constantly increased, in 1986 the aluminum can was used as the container for only 30 percent of soft drinks sales. Its competitors were, again, the returnable glass bottle (which had just under 20 percent of the market), the non-returnable glass bottle (10 percent), the plastic bottle (20 percent) and the steel can (less than 3 percent). The remainder consists of unpackaged sales, an increase which reflects the rise in the consumption of soft drinks in fast food chains. While for soft drink packaging overall there is greater competition among different materials than for beer packaging, within the canned soft drink market, the aluminum can dominates with a 90 percent share. In the food can materials market, however, aluminum has not made any significant penetration; in 1986, its share of that market reached only 6 percent.[39]

Although the aluminum can has had great success, the American aluminum industry cannot expect future growth in this end-use market comparable to that

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[39] This can be explained by two reasons, the first being related to technology. Food cans have different requirements than beverage cans. They must be able to withstand internal pressure without collapsing during high-pressure vacuum processing. Also, they must have durability for storage and multiple handling, which at present aluminum cans do not have. The second reason is related to the absense of economies of scale in the food can market. Food cans are not standardized with respect to shape and volume. And, unlike the situation in the beer market, the relative market size of each food can user is too small to permit the distribution of the high capital cost of new filling equipment over a great volume. For further reading on this subject, see: C. Nappi (1987), "Metals Demand and the Beverage & Food Industry: The Case of the United States and a Comparison with Other Industrialized Countries", paper presented at the *World Metal Demand Workshop* sponsored by Resources for the Future and the Colorado School of Mines, Helsinki, Finland, October 12-13.

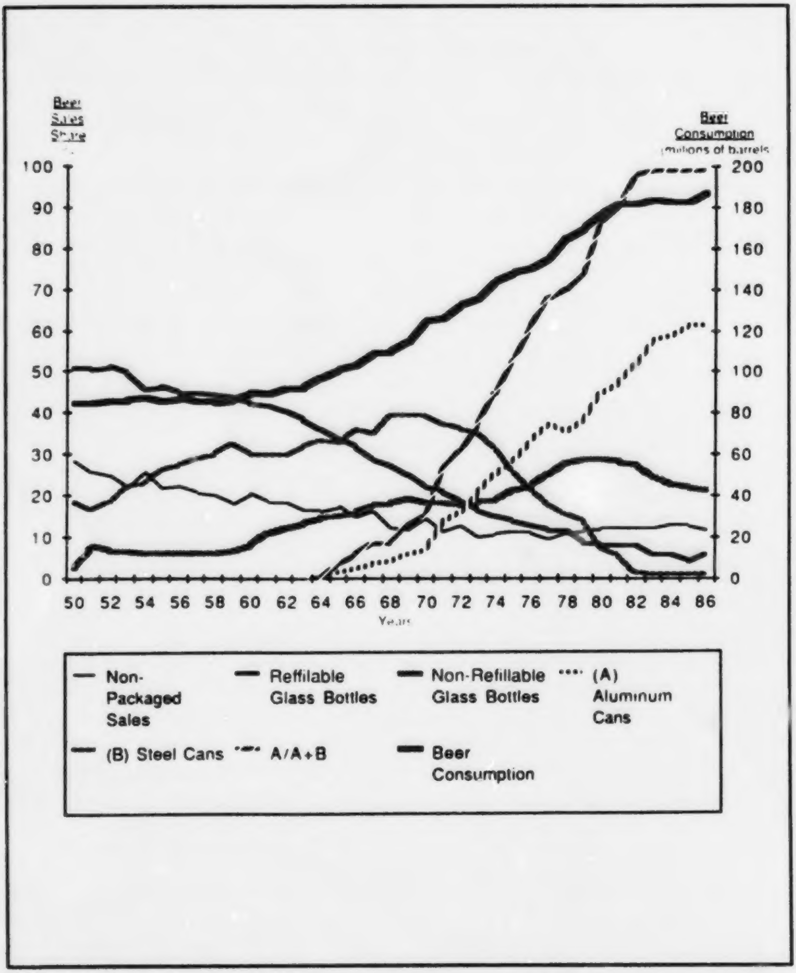

Figure 9. Breakdown of U.S. beer sales by package type: 1950-86 (in million barrels and percent)

Source: figures derived from: *Beverage Industry*, Magazines for Industry Inc., Minnesota, monthly, various issues; *Beverage World*, Keller Publishing, East Stroudsburg, Pa., monthly, various issues; Demler, F.R., *The nature of tin substitution in the beverage container industries*, Ph. D. Thesis, The Pennsylvania State University, August 1980, pp. 171-172; *The Food and Beverage Market*, Business Trend Analysts Inc., Commack, New York, 1983, p. 103.

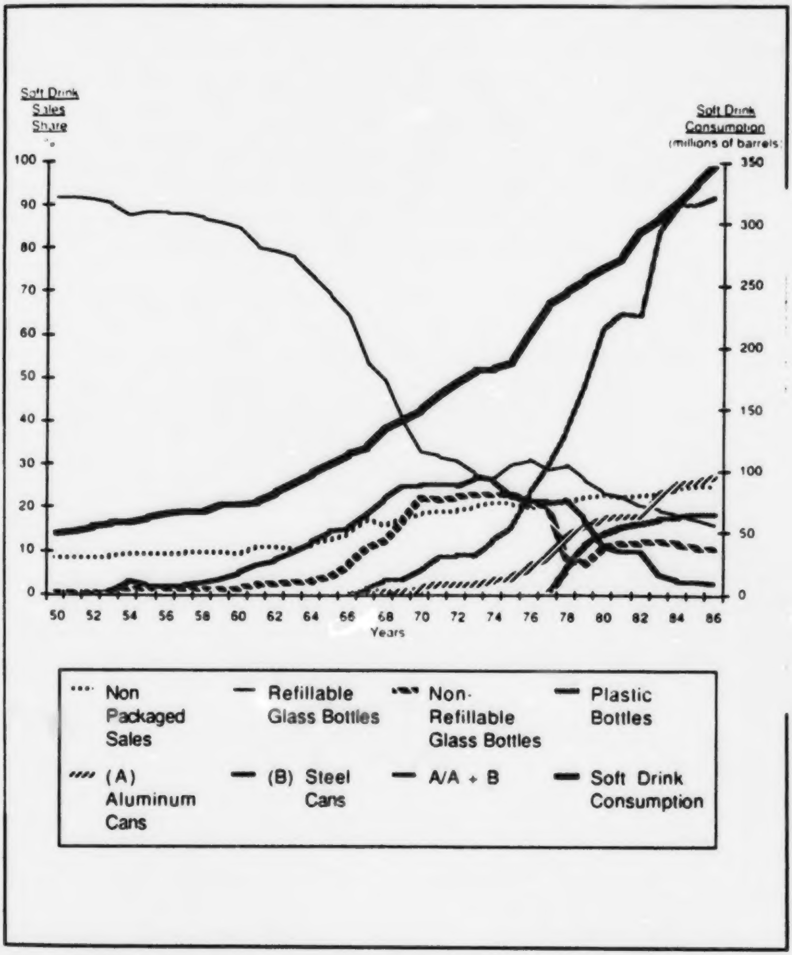

Figure 10. Breakdown of U.S. soft drink sales by package type: 1950-86 (in million barrels and percent)

Source: figure derived from: *Beverage Industry*, Magazines for Industry Inc., Minnesota, monthly, various issues; *Beverage World*, Keller Publishing, East Stroudsburg, Pa., monthly issues; Demler, F.R., *The nature of tin substitution in the beverage container industries*, Ph. D. Thesis, The Pennsylvania State University, August 1980, pp. 169-170; *The U.S. soft drink market*, Business Trend Analysts Inc., Commack, New York, 1984; *The food and beverage market*, Business Trend Analysts Inc., Commack, New York, 1983, p. 103.

of the 1970s. This is for two simple reasons. First, as the aluminum can already almost totally dominates the metal can market, there is little scope for further growth at the expense of the steel can; growth can occur only as a result of increases in total beer and soft drink sales. What about foreign markets and the chance of repeating there the American success? A study we recently did on this subject[40] revealed that the aluminum can has had limited success in penetrating those markets[41] for several reasons: the fragmentation of the European beer market; the very strong resistance of European, Japanese and Canadian glass bottle producers; government legislation favouring the production and use of recyclable or returnable containers; consumer preferences, etc., and therefore it may never be as successful there as it has been in the United States.

Second, in order to penetrate the beer and soft drink container market and maintain a significant presence there, the aluminum can industry has had to constantly control its production costs. Cost reduction has focused on gauge reductions in the can body and lid stock, reduction in the thickness of finished can walls, the development of double- and triple-necked containers in order to reduce the diameter and thus the cost of ends, the development of higher-strength alloys which would allow for further lightweighting of both body and ends, and the like.

Figure 11 shows the results of these efforts: we can see that since 1960, the weight of aluminum cans has decreased by more than 40 percent (for steel cans it has decreased by almost 60 percent). This reduction has come about because of the gauge reduction of the can body and lid stock. While in 1970, the average gauge for body stock was 0.017 inch, it has constantly decreased since then, reaching 0.014 inch in 1975, 0.0135 inch in 1980, 0.013 in 1985 and 0.0126 in 1987. According to industry spokesmen, by 1990 the gauge is expected to decrease to 0.012 inch. In the case of end stock, the current gauge is 0.010 inch and by 1992 should reach 0.008 inch. This leads us to conclude that despite a strong increase in aluminum consumption in the beverage market, this growth could possibly have been even greater had there not been an effort to reduce the metal content in manufacturing. We say "possibly" because without that

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[40] C. Nappi (1987), *op. cit.* section 3.

[41] In 1985, this was the situation with regard to aluminum cans:

	Proportion of Sales in Cans		Ratio of Aluminum Cans to Total Cans	
	Beer	Soft Drink	Beer	Soft Drink
United States	62%	29%	99%	90%
Western Europe	6-13%	15-30%	35%	35%
Japan	17%	30%	91%	31%
Canada	12%	30%	100%	33%

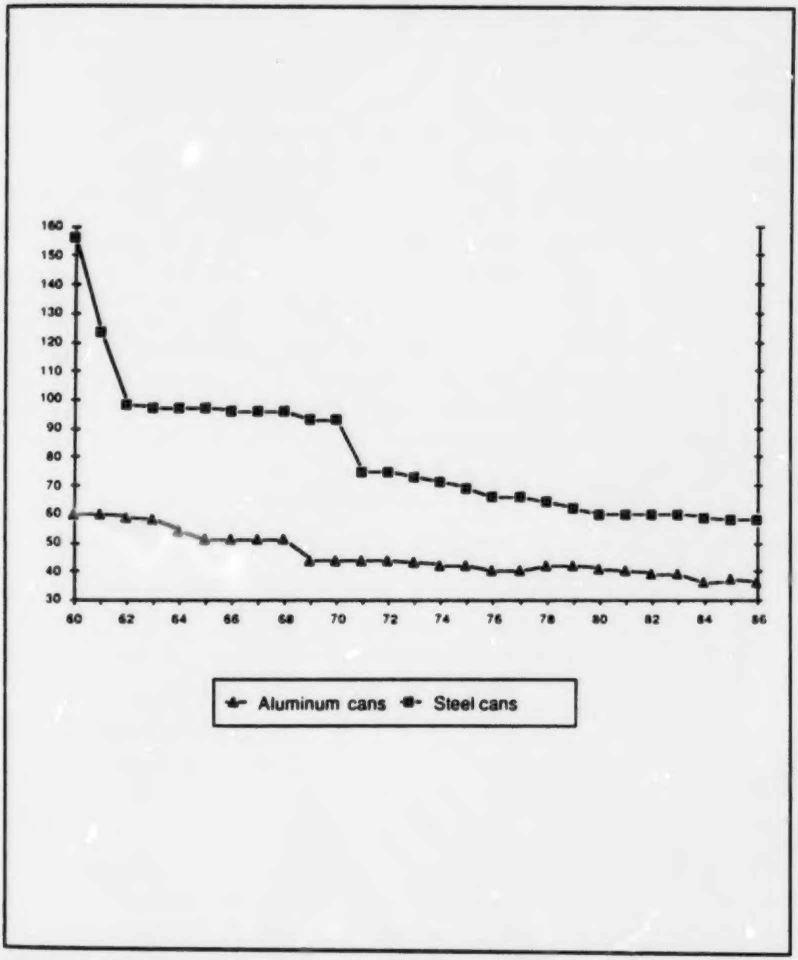

Figure 11. Aluminum and steel can weights (lbs per 1,000 cans)

Source: figure derived from: Demler, F.R., *Beverage Containers*, in J.E. Tilton (ed.), *Materials substitution: lessons from tin-using industries*, Resources for the Future Inc., Washington, D.C., 1983, pp. 17-19.

We are grateful to F.R. Demler who also provided the data on steel can weights.

effort aluminum cans would not have so easily pushed the steel can out of the market. There is no reason to believe that technological efforts aimed at reducing the thickness of the aluminum sheets used for producing aluminum cans will be less intensive in the future than they have been in the past.

Growth in total aluminum consumption slackened in the USA around the mid-1970s, although this decline was barely felt because of the success of the aluminum can. However, as the can came to dominate the metal containers market and producers continued to reduce costs by favouring production technologies less intensive in aluminum in order to resist pressure from competitors, it became apparent that the aluminum can would no longer be able to mask the decline in aluminum consumption that was occurring in other end-use markets. In fact, the can appeared likely to contribute to future declines in aluminum consumption. Of course, it is possible that an upsurge will occur in aluminum consumption by the metal cans market in various industrialized or developing countries, or even in the United States, particularly if aluminum-plastic/paper laminates are accepted for packaging of food and beverages. There is little reason, however, to think that this will happen soon.

TRANSPORTATION

We stated earlier that the share of aluminum shipments to the transportation sector has remained relatively stable during the last quarter century; in 1970, it hit a low of 17 percent, then stabilized at around 20 percent. Over the years, consumption by this sector has increased at a rate similar to total consumption, about 8 percent per year. Aluminum consumption in car production grew at about the same rate, with shipments to that market rising from just over 160,000 tonnes in 1960 to about 500,000 tonnes in 1986.

Since 1973, aluminum consumption by the car industry has slackened its growth to barely exceed 3 percent per year, which helps to explain the very moderate growth in total aluminum consumption observed for this period (figure 2). The reasons for the reduced growth of aluminum consumption by the automobile sector in the United States, Japan and West Germany have been studied by R. Eggert,[42] as well as N.A. Gjostein.[43] Eggert's starting point is an identity showing that the consumption of various materials (among them, aluminum) by the automobile industry can be obtained by multiplying total car production (for the domestic as well as the foreign markets) by the quantity (in number of pounds) of each material used per car. Any changes occurring in the first variable result largely from changes in macroeconomic factors: income, demographic trends, costs of vehicle ownership, geographic and institutional factors, and so on. Variations in the second variable reflect technological changes in the production process or changes in car design (which affect a car's average weight or its material composition).

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[42] R.G. Eggert (1987), "The Passenger-Car Industry", paper presented at the *World Metal Demand Workshop* sponsored by Resources for the Future and the Colorado School of Mines, Helsinki, October 12-13; R.G. Eggert (1986), "Changing Patterns of Materials Use in the U.S. Automobile Industry", *Materials and Society*, vol. 10, no. 3, pp. 405-432.

[43] N.A. Gjostein (1986), "Automobile Materials Usage Trends", *Materials and Society*, vol. 10, no. 3, pp. 369-404.

It appears from Eggert's and Gjostein's investigations that the decrease in the consumption of aluminum (and steel) by the world car industry is chiefly the result of slower growth in the production of passenger cars rather than of fewer pounds of aluminum being used per car. In fact, pounds of aluminum per car rose quite considerably between 1960 and 1986, increasing worldwide from 50 to 124 pounds per car, or by 5.5 percent annually.[44] In the United States, that growth was slightly higher (5.8 percent), as the amount of aluminum used per car increased from 54.4 to 139.5 pounds during the same period. Eggert attributes this performance to aluminum's increased share of the weight of a car. He writes:

> For aluminum, pounds per car rose for all three countries between the 1960s and the 1980s, more than doubling in the United States and Germany, while increasing slightly less in Japan. These increases are attributable almost entirely to aluminum's increased share of the weight of a car. In absolute terms, U.S. cars have had more pounds of aluminum than German or Japanese cars over almost the entire period. For plastic and composite materials, pounds per car also rose for all three countries between the 1960s and the 1980s, again due almost entirely to increased shares of new car weight. But the magnitude of change has been much greater for plastics and composites than for aluminum, increasing five to ten times over the period. In addition, only since the early to middle 1970s have U.S. cars had more pounds of material per car than their German and Japanese counterparts.[45]

Although the slowed growth of aluminum consumption by the automobile industry is attributable more to such cyclical causes as slower growth in car production because of slower growth in national income than to structural factors such as the material composition of a passenger car or variations in its weight, since the beginning of the 1980s, per car consumption of aluminum has been increasing much more slowly. This is a reversal of the earlier trend: between 1960 and 1975, aluminum's share of a car's weight increased as engineers adopted the light metal for castings in pistons and clutch housing, grilles, interior and exterior trim, transmission housings, master cylinders, water pumps, intake manifolds, automatic transmissions and air conditioning. This substitution grew even more intense around the mid-1970s, as a result of the energy crisis which pushed American producers to reduce the weight of their cars in order to respond to consumer demand and satisfy government regulations aimed at reducing consumption of fuel. At that time, aluminum's share of the weight of a typical American car rose from 2 percent to 5 percent, as cast aluminum continued to replace cast iron in engine parts, transmission housings, brake drums and elsewhere and wrought aluminum was substituted for steel in hoods and other outer-body panels and in bumpers.

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[44] R.G. Eggert (1987), *op. cit.*, statistical appendix.

[45] R.G. Eggert (1987), *op. cit.*, pp. 20-21.

Since 1980, however, aluminum consumption per car has grown by only 2.3 percent per year in the United States, 1.6 percent in West Germany and 2.8 percent in Japan. In fact, the metal has lost some of its newly-acquired uses in grilles, exterior trim, bumpers, engine components, luggage load floors and other parts to plastics and composite materials, which are cheaper to produce and more resistant to corrosion. In the typical American car, the weight of plastic and composite products has increased from 35 pounds in 1960 to 196 pounds in 1986, an average annual growth of 17 percent (28 percent in West Germany and 17 percent in Japan). In addition, the share of a car's weight held by high-strength steel increased in the mid-1980s from 0 percent to more than 7 percent. It is used in outer-body panels to save weight and thus improve fuel economy, and in body panels, structural parts, wheels, suspension arms and other applications where aluminum could have been used. Another reason for the reduction of aluminum use in American car production is that its use in such parts as engine blocks, cylinder heads, intake manifolds and, especially, radiators has been delayed.[46]

Thus, we can conclude that although inter-material or intra-metal substitution is not the main cause of the slowdown in the growth of aluminum use in the car production sector, aluminum's share of the weight of a car might have been much greater had plastics, composite products, HS steels and, recently, magnesium not given it such stiff competition. It was substitution that enabled aluminum to grab for itself a large share of the market (about 5 percent) early on; since the beginning of the 1980s, it is, again, substitution that appears to be slowing down aluminum's rate of penetration. Also contributing to the slowdown have been technical and institutional factors that have delayed the introduction into North America of automobile parts which in Europe and Japan have been made of aluminum for the past several years. Substitution has also affected aluminum use in the aeronautics and aerospace industries, where it has been replaced in several applications by carbon/graphite composites. The aluminum industry has reacted by developing a new aluminum-lithium alloy, which it hopes will halt the decline and enable aluminum to hang on to its share of the market.

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[46] The radiator market offers aluminum substantial growth potential. However, aluminum radiators have two disadvantages when compared to copper: they are more difficult to produce and more difficult to repair. Still, the trend, even for copper radiators, has been to do less repair each year, but, rather, to exchange old radiators for new ones. In addition, the early problems encountered in producing aluminum radiators have been overcome through technology.

BUILDING AND CONSTRUCTION

During the last twenty-five years, American shipments of aluminum to the building and construction sector have increased less rapidly (by 5.6 percent per year) than total shipments; their relative share has diminished steadily, from 29.6 percent in 1960 to 21.1 percent in 1987. Since 1973, shipments to this sector have been decreasing, growing on average by -1.2 percent per year, which has certainly contributed to the atrophy of total consumption of aluminum.

The main reason for this decline has been the displacement of aluminum by vinyl in the residential siding market. This substitution began to occur around the mid-1970s, when aluminum's price advantage over vinyl disappeared. By 1982, U.S. shipments of vinyl siding exceeded those of aluminum siding. In addition to being lower in price, vinyl siding has the advantage of having the color distributed throughout the material and being less prone to marring by scratches and dents. Also displacing aluminum have been some traditional siding materials, like wood, which are regaining the share of the market they had lost during the 1970s.

ELECTRICAL AND ELECTRONIC EQUIPMENT

Because of the substitution of aluminum for copper in high-voltage electric transmission lines, the share of total American aluminum sales held by this sector rose to a peak of over 15 percent in the early 1970s; after that, it steadily diminished, dropping by 1987 to 9.2 percent. Although for the whole period 1960-87, aluminum consumption by this sector grew on average by 6.2 percent per year (the peak was reached in 1973, with 841,200 tonnes), since 1973, that growth has declined to -1.7 percent annually.

This falloff in aluminum consumption can be explained by the miniaturization of electronic equipment, which has substantially reduced the amount of aluminum consumed per unit produced, the substitution of aluminum, primarily by plastics, and the slowdown in the construction of above-ground high-voltage electric transmission lines (mainly as a result of the economic recession which cut down energy consumption). Furthermore, the success that had been predicted for aluminum in household wiring applications never materialized. Even today, in spite of the fact that correctly-installed aluminum wiring does not pose a fire hazard, building codes in many areas forbid it. The aluminum industry has tried to change the negative image of its wiring by introducing copper-clad aluminum wire, which reduces the chance of fire breaking out because of incorrect installation, but the success of that initiative has been rather limited.

Table 5:
Apparent Consumption of Copper Mill Products: USA, Various Years (percent)

Mill Products	1960	1965	1970	1975	1980	1987
Wire mill products						
Bare wire	4.1	3.3	3.8	3.5	3.4	2.3
Communication wire and cable	31.0	8.6	12.4	12.0	14.4	8.7
Building wire		23.0	8.2	9.9	10.6	16.5
Magnet wire			7.9	6.9	7.5	7.4
Power cable			4.6	4.4	4.6	3.7
Apparatus wire and cordage			2.3	2.9	3.6	3.1
Automotive wire and cable (exc. magnet)			1.1	1.4	1.5	3.2
Other insulated wire and cable			1.1	1.7	1.5	1.2
Total	35.1	34.9	41.4	42.7	47.1	46.1
Brass mill products						
Strip, sheet and plate	15.2	16.4	14.9	17.1	14.8	12.5
Mechanical wire	14.7	2.2	1.9	1.3	1.4	0.9
Rod and bar		13.2	11.7	12.0	13.7	13.4
Plumbing tube and pipe	6.8	9.3	6.4	6.4	7.0	8.6
Commercial tube and pipe	6.7	6.6	7.5	5.5	6.0	5.2
Total	43.4	47.7	42.4	42.3	42.9	40.6
Total foundry products	17.6	14.4	13.2	13.0	9.7	7.7
Total powder products	0.9	1.0	0.8	0.9	0.6	0.6
Net imports of mill products	3.0	2.0	2.2	1.1	-0.3	5.0
Total Mill Products to Domestic Market (,000 tonnes)	100.0 (1,965.9)	100.0 (2,826.8)	100.00 (2,660.2)	100.00 (2,192.2)	100.00 (2,655.3)	100.00 (3,086.9)

Source: Copper Development Association Inc., *Copper Supply & Consumption*, Annual Data, Greenwich, Connecticut, various issues.

Copper

Unlike aluminum, copper and its principal alloys (bronze and brass) have been playing a role in the economic development of human societies for thousands of years. Because of copper's properties: thermal and electrical conductivity; ductility; resistance to corrosion; durability and versatility of form - world consumption of the metal grew annually by about 3.5 percent between 1960 and the beginning of the 1970s. In the United States, the apparent consumption of copper mill products reached a high point in 1973 of 3.15 million tonnes, a level which has never been surpassed (except perhaps in 1988), since consumption has stagnated both in the USA and elsewhere, growing annually by less than 1 percent.

Table 5, which shows the relative importance in the United States of semi-manufactured products based on copper, will demonstrate the reasons for that stagnation. According to that table, electrical wire has been growing in importance among copper mill products. While it accounted for about 35 percent of apparent copper consumption at the beginning of the 1960s, its share of the market presently fluctuates between 45 percent and 47 percent, and, since 1973, it has been growing at a higher annual rate (1.1 percent) than copper mill products as a whole (0.1 percent per year). Further, the table shows us that the increase in the market share held by wire mill products is attributable mainly to building wire: its share grew from 8.2 percent in 1970 to 16.5 percent in 1987. On the other hand, the share held by communication wire and cable dropped during the same period from 12.4 percent to 8.7 percent. Although the other types of copper wire have been relatively less important, it is worth noting that the market share of automotive wire and cable has been growing (from 1.1 percent to 3.2 percent between 1970 and 1987) and that of bare wire and power cable has been shrinking. Although the relative importance of copper wire mill products has increased during the last eighteen years, the 1.1 percent annual growth rate they showed during 1973-87 was much lower than their 4.9 percent growth during 1960-73. We will consider the structural causes of this decline later.

The apparent consumption of brass (copper and zinc) mill products has grown less rapidly (-0.9 percent per year) since the beginning of the 1970s than has total consumption of copper mill products; as a result, their share of the market has decreased. The present growth rate for these products is lower than during 1960-73, when it was 2.6 percent per year. The reasons for the decline include substitution, downsizing of end products and an increased use of copper-saving technologies in the principal sectors of the products' use. Most notably affected by the slowdown in growth is the main brass mill product, strip, sheet and plate, which, after growing by 2 percent per year during 1960-73, declined during 1973-87 to an annual growth rate in consumption of -2.2 percent. At present, the dominant product in this category is rod and bar, its market share having stabilized at around 13.5 percent. The market share held by plumbing tube and pipe has been growing since the beginning of the 1970s and now hovers around 8 percent.

Copper foundry products (especially those produced with sand castings) reached their peak on the American market relatively early, around the mid-1960s (420,000 tonnes in 1966), and ever since have been diminishing in importance. In 1987, they barely topped 235,000 tonnes, showing an annual growth rate of -3.3 percent. Not surprisingly, the market share of these products has decreased, falling from over 17 percent of apparent consumption of copper mill products at the beginning of the 1960s to 7.3 percent in 1987. Although net imports of these products have not held in the past a large share in the apparent consumption of copper-based semimanufactured products, they comprised in 1987 about 5 percent of the total.

In order to understand the structural causes of the atrophy observed in the consumption of copper, we must examine not only the production of copper-based semimanufactured goods, but also the end-use markets for which they are intended. With regard to the former, relatively homogeneous and consistent statistical data can be found; such is not the case, however, with regard to end-use markets. Thus, for example, one source of information (publications of the Copper Development Association[47]) tells us that the building and construction end-use market — plumbing and heating; building wiring; air conditioning and commercial refrigeration; builders' hardware; architectural — is becoming the principal outlet for American copper mill products. Its market share, according to that source, has increased to 43 percent in 1987, compared to 22.5 percent in 1960, and it appears to be the only end-use market to have grown. By contrast, the electrical and electronic products sector — telecommunications; power utilities; lighting and wiring devices; and business electronics — seems to be declining, its market share having decreased to 22 percent, compared to 26 percent at the beginning of the 1960s. Even greater decreases in market share are attributed to the industrial machinery and equipment sector — in-plant equipment; industrial valves and fittings; heat exchangers; off-highway vehicles; and non-electrical instruments — and the consumer and general products sector — appliances, fasteners and closures; military and commercial ordnance; coinage; consumer electronics; and utensils and cutlery — the respective shares of which are said to have shrunk almost by half during the last 27 years, reaching levels in 1986 of 13.6 percent and 9.6 percent respectively. Shipments of copper mill products to the transportation equipment market — automobile, truck and bus; railroad; marine; aircraft and aerospace — are said

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[47] Copper Development Association Inc., *Copper Supply and Consumption*, Annual Data, Greenwich, Connecticut, table 4, various issues.

Table 6:
Copper Consumption by Class of Customers: USA; 1974, 1979, 1984
(Thousand tonnes and percent)

SIC	Use	1974	1979	1984	CAGR [a] 1974-84
1600	Heavy construction	518.9 (26.1%)	575.2 (26.7%)	544.3 (26.7%)	0.5
1700	General construction	492.6 (24.8%)	534.3 (24.8%)	505.3 (24.8%)	0.3
2800	Chemicals	0.9	0.9	0.9	-
3300	Primary metals	4.5	7.0	4.5	-
3429	Hardware	20.0	20.0	19.0	-0.7
3432	Plumbing fittings	43.5	44.5	40.8	-0.6
3433	Heating equipment & elec.	12.7	12.7	11.8	-0.6
3440	Fabricated metal work	13.6	13.6	12.7	-0.7
3450	Screw machine, nuts, bolts	28.1	29.0	27.2	-0.4
3469	Stamping, including coinage	37.2	37.2	35.4	-0.6
3482	Ammunition	11.8	11.8	11.8	-0.2
3510	Engines & turbines	43.5	47.2	44.5	0.2
3530	Construction machinery	17.2	19.0	18.1	0.5
3540	Metalworking machinery	17.2	18.1	18.1	0.3
3550	Special industrial machinery	27.2	29.9	28.1	0.4
3560	General machinery	42.6	46.3	44.5	0.3
3570	Office machines	13.6	15.4	14.5	0.7
3585	Air conditioning & heating Equipment	100.7 (5.1%)	104.3 (4.8%)	98.9 (4.9%)	-0.2
3612	Transformers	16.3	18.1	17.2	0.6
3613	Switchgear	20.0	21.8	20.0	0.2
3621	Motors and generators	36.3	39.9	37.2	0.3
3630	Household appliances	79.8 (4.0%)	88.0 (4.1%)	82.6 (4.1%)	0.4
3640	Lighting & wiring equipment	51.7	55.3	51.7	0.1
3660	Communications equipment	62.6	69.9	65.3	0.5
3670	Electronic components	36.3	39.9	38.1	0.4
3694	Engine electronic equipment	17.2	19.0	17.2	0.2
3699	Electrical NEC	13.6	15.4	14.5	0.4
3710	Motor vehicle parts & accessories	158.8 (8.0%)	169.7 (7.9%)	159.7 (7.8%)	0.1
3720	Aircraft	16.3	18.1	17.2	0.4
3730	Shipbuilding	10.0	10.9	10.0	0.2
3743	Railroad	8.2	9.1	8.2	0.4
3790	Other transportation	8.2	9.1	9.1	0.8
3800	Measuring & control	6.4	7.0	7.0	1.1
Total		1,987.7 (100.0%)	2,158.2 (100.0%)	2,035.8 (100.0%)	0.2

[a] Compound annual growth rate

Source: U.S. Department of Commerce (1986), ***The End-Use Markets for 13 Nonferrous Metals***, Nonferrous Metals Division, Office of Metals, Minerals and Commodities, Washington, June, p.23.

by the same source to have increased at the same rate as total copper consumption, with a market share fluctuating around 12 percent.

However, other sources of information paint a different picture of copper consumption by end-use markets. Thus, data published by Brook Hunt and Associates, cited in a recent publication of the World Bank,[48] indicate that the main outlet for copper shipments is the electrical products sector, including telecommunications, which is said to account for about 50 percent of copper consumption, not only in the United States, but also in Japan and Western Europe. The second most important outlet, according to this source, is not construction (15 percent on average in each of the three regions), but rather, the general engineering sector, which is said to account for over 18 percent of copper consumption. The transportation and domestic uses sectors are said to split between them the remaining copper shipments, holding a market share of less than 10 percent.

Statistical disagreements of this sort are not unexpected, given that the sectors in which copper is used are variously defined. Rather than follow one or the other of the sets of definitions referred to above, we will base our discussion of the structural causes of the atrophy of copper consumption on a broader classification system that is recognized by the U.S. Bureau of Mines. In table 6, we show the evolution over time of the consumption of refined copper in the United States according to class of customers as defined by the Standard Industrial Classification (SIC) Code. The table shows us that about 70 percent of American consumption of copper is concentrated in five of thirty-three industries listed: heavy construction (SIC 1600); general construction (SIC 1700); air conditioning and heating equipment (SIC 3585); household appliances (SIC 3630); and motor vehicle parts and accessories (SIC 3710). Let us look more closely at the use of copper in each of those five consuming industries:

Heavy Construction (SIC 1600). In this sector, copper is used in making wire, sheet and tube for use in heavy construction work such as erecting electrical and communication transmission lines, building railroads, street maintenance, marine construction and other construction except that of buildings. The annual growth rate of copper consumption by the industries grouped in this vast sector was higher during 1974-84 (0.5 percent) than that of total copper consumption (0.2 percent), which suggests that substitution is proceeding less rapidly in this sector now than it did during the 1950s and '60s. Let us look more closely at the communication wire and electrical cable markets.

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[48] K. Takeuchi, J.E. Strongman and S. Maeda (1986), *The World Copper Industry: Its Changing Structure and Future Prospects*, World Bank Staff Commodity Working Papers, no. 15, Washington, p. 48.

For many years, copper wire has been the favoured transmission medium for telephone *communications* systems. Although various new communications technologies have recently appeared — microwave, satellite, and coaxial cables, among others — copper wire used in telecommunications still accounts for 20 percent of all copper consumption in wires and cables and about 10 percent of all copper consumed in the United States, Japan and Western Europe.[49] This relative stability, in spite of the proliferation of new means of telecommunications which use much less copper, is a result of the large customer base served by communication wire and the development of new markets. The very rapid growth of cable television during the past decade has created a growing market for large quantities of flexible and semiflexible coaxial cable.

Nevertheless, copper's market share in the communications sector is definitely threatened by the ever-growing invasion of optical fibre cables. Although the impact of optical fibre on copper consumption has so far been only moderate, it is unlikely to remain so in the future. Optical fibre technology is superior to that based on copper wire; it offers a means of communication that is more powerful, more effective, more precise and, in most cases, more economical. Until recently, optical fibre has been used mainly in high-signal-density applications, such as long distance and inter-office trunking.[50] In the local feeder and distribution loop of the telephone network,[51] where most of the copper telecommunication cables are used, the use of optical fibre has been very limited. One reason for this unequal penetration of the different parts of the telephone network by optical fibre is its relatively high cost. However, its present price disadvantage relative to copper wire (about 10 percent) is likely to disappear in future. Already the cost of optical fibre has decreased from U.S. $0.41 per fibre meter in 1984 to U.S. $0.17 at the beginning of 1987; by the beginning of the 1990s it is expected to drop to U.S. $0.10 per fibre meter.

If this proves to be the case, copper may experience substantial losses in the feeder loop, where 70 percent of all copper-based telecommunication wire and

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[49] K. Takeuchi, J.E. Strongman and S. Maeda (1986), *op. cit.*, p. 160.

[50] Given that in long-haul transmission, optical fibre systems require fewer repeaters/boosters than copper-wire systems, it seems almost certain that optical fibre will totally replace copper in this application.

[51] A World Bank publication describes the telephone network as follows: A local loop consists of two subsegments, i.e. the feeder loop, which extends from central exchanges to concentration and branching points and the distribution loop, which connects branching points and subscribers' homes or business offices. In the feeder loop, in which 70 percent of all copper-based telecommunication wire and cable is used, new additions are likely to be increasingly in optical fibers because, despite the estimated 10 percent higher cost, optical fiber cables have the advantages of unlimited bandwidth and much greater reliability. K. Takeuchi, J.E. Strongman and S. Maeda (1986), *op. cit.*, pp. 161-162.

cable is used. In the distribution loop segment of the local loop, where 24 percent of all communication wire and cable is installed, the losses will probably be less dramatic. This is because:

> . . .there are a number of obstacles which militate against provision of optical fibers to residential customers, economics being the main problem at present. One educated guess is that in the United States only 1 percent of residential loops will use optical fibers by 1990 and at best 20 percent by 1995, and for business customers a 50 percent penetration rate on new lines may be envisaged by 1995. Thus, copper losses due to fiber optics in the distribution loop are not likely to be substantial, at least up to 1995.[52]

To sum up, although copper has been or soon will be completely displaced by optical fibre in two of the three segments of the telephone network (long-distance and inter-office trunking), the effects of this substitution on copper consumption have so far been quite limited, as those markets account for barely 7 percent of all copper-based telecommunication wire and cable. Things will look different, however, when optical fibre replaces copper in the local feeder and distribution loop. It is expected that by 1990, fibre optics will displace 40 percent of the copper used in the telecommunications industry, and by 1995, 70 percent.[53] This substitution will probably result in substantially more scrap copper, with all that implies for copper prices and production capacity. We should point out that in addition to substitution by optical fibre, copper consumption in this market has also slowed down because of technological changes. For example, multiplexing in telecommunications has multiplied the transmission capacity of copper telecom cables, thus reducing the per unit requirement for copper. Other examples are the increasing use of microwave transmission and of integrated circuit systems.

One segment of the heavy construction market in which substitution has already had a tangible (and not only potential) effect is the *electrical cable market*. For purposes of electrical conductivity, aluminum has always been a possible substitute for copper;[54] it began to be used as such around the beginning of the 1950s, when it became less expensive per unit of weight than copper. That price difference increased through the 1950s and 1960s, thus accelerating the substitution of copper wire by aluminum. The share held by aluminum in the consumption of copper and aluminum (in electrical equivalency) for cable manufacturing rose from 7.5 percent in 1964 to 25.8 percent in 1973 in the member countries of the International Cable Development Corporation (ICDC) and the International Telephone Cable Development Association (ITCDA),[55] and in Japan.

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[52] K. Takeuchi, J.E. Strongman and S. Maede (1986), *op. cit.*, p. 162.

[53] Brook Hunt Associates, *Copper Quarterly Services*, XV, July, 1984; Hugh Douglas & Co., *The Impact of Fiber Optics on Copper Wire Markets*, a multiclient report, San Francisco, 1982.

[54] It is often noted that aluminum wire weighs about 50 percent as much as copper wire for an identical electrical conductivity. However, because of its greater volume, aluminum wire requires more insulation; furthermore, its ductility and mechanical properties are inferior to those of copper. For these reasons, copper needs to be only 35 percent (rather than the theoretical 50 percent) cheaper than aluminum (per unit of weight) to be competitive.

However, since the beginning of the 1970s, aluminum's penetration into the electrical cable market has slowed down. It continued to increase at a modest rate until 1980, when its share of the market peaked at 30 percent, then stabilized at around 27 percent. The reason for this slowdown is that aluminum use in electrical cables (61,000 tonnes in 1964; 684,000 tonnes in 1980; 512,000 tonnes in 1984)[56] has been concentrated in the high voltage power wire market; in household wiring, copper has regained its competitive position. As we mentioned earlier, aluminum wiring, introduced during the 1960s, declined dramatically during the 1970s, when it came to be considered a fire hazard (although, in fact, problems arise only when aluminum wiring is installed with outlet boxes and brass screws designed for copper wiring). As a result, copper substitution by aluminum in the electric cable market was significant during the 1950s and 1960s, but since the beginning of the 1970s, has been slowing down considerably.

General Construction (SIC 1700). Included in this category is all the copper used in work done by special trade contractors, more specifically the copper and copper alloys used in the production and the transportation of electric power at the site, communication wire and connectors, water carrying and sprinkler systems, central air conditioning equipment, heating systems, roofing and other uses. The construction sector has been for many years one of the principal outlets for brass alloys and other copper-based products and copper's position in this market still remains enviable. It is used heavily both in the construction of new houses and commercial buildings and for renovation.

Nevertheless, in this market too, the substitution of copper by other metals or materials is having a serious effect. Various types of plastics (among them, polyvinyl chloride, PVC, and polybutylene, PB) have replaced copper in hot and cold water distribution systems (tubing, plumbing, toilet fittings, guttering pipes) and other miscellaneous copper and brass products such as door knobs and locks. This process of substitution became particularly marked near the end of the 1970s, as real prices of plastics decreased and new varieties were introduced. The process is far from over; even greater damage to copper can be expected from plastics in the future.

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[55] The members of the ICDC/ITCDA are: Austria, Belgium, Denmark, Finland, France, Federal Republic of Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, India, Israel and South Africa.

[56] During the same period, the consumption of copper did no better than double, from 755,000 tonnes to 1,533,000 tonnes.

Still, it would not be true to say that all segments of the construction sector are declining markets for copper products. For example, the roofing market, which includes shingles for houses, motels and industrial buildings and sheet roofing for high-rise and other commercial buildings, is in full expansion. Given copper's tremendous resistance to variations in temperature, its durability and its ease of installation, it is likely to hold this market for a long time to come. Furthermore, in institutional buildings (hotels, hospitals, nursing homes and the like) copper fire sprinkler systems are overwhelmingly preferred in spite of the fact that substitutes are available, because the copper products are easier to install and of better quality. Yet another market in expansion is that of large-diameter copper tubes for water supply systems in commercial buildings. In some segments of this market, copper is not merely resisting substitution, but is even taking the offensive. Thus, in Europe we find copper tubes substituting for black iron, galvanized and lead pipes.Still, in spite of such cases of resistance, copper's substitution by plastics in several segments of the construction sector has contributed to a slowdown in consumption. Thus, in table 5 we see that the share of apparent copper consumption held by plumbing and commercial tube and pipe has decreased. That decline has been felt much more in North America than in Europe because of differences in building codes and industry practices:

> . . .substitution in the construction industry will proceed faster in the United States than in Western Europe. In the United States, building regulations have generally been less rigid in their requirements about materials, and this has allowed rather more substitution. In Western Europe, in addition to stricter building codes, the practice of sub-contracting electrical and plumbing jobs to small firms, which may be experienced with only a limited range of materials, limits the pace of substitution.[57]

During 1974-84, shipments of copper to the construction sector increased at a slightly higher rate (0.3 percent per year) than the annual growth rate of American consumption as a whole (0.2 percent per year). While this might be worth noting, it is not really a cause for celebration, for it has not prevented copper's index of intensity of use from decreasing. At best, copper producers can be thankful that at least in the heavy and general construction sector copper has fared less badly than elsewhere.

Air Conditioning and Heating (SIC 3585). In this sector we have the air conditioning and heating units bought by consumers (central air conditioning and heating systems installed in commercial buildings were considered in the previous section). During 1974-84, this market grew at an annual rate of -0.2 percent, absorbing, in 1984, just under 5 percent of the total American consumption of copper. The main reason for this poor performance was the sharp increase in energy prices, which led consumers to demand more energy-efficient products and producers to offer smaller and better-insulated air conditioners.

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[57] W. Glushke, J. Shaw and B. Varon, *Copper: the Next Fifteen Years*, D. Reidel Publishing Company, Boston, 1979, p. 41.

In this market then, the main cause of atrophy in copper consumption has not been substitution, but general downsizing and miniaturization of products. There has been some substitution of copper parts by plastic or metals, but this has not proved very significant. Another factor in the decline of copper use has been the poor overall performance of the economy, which together with high interest rates, has slowed down residential construction.

Household Appliances (SIC 3630). In the mid-1980s, this sector accounted for about 4 percent of American consumption of copper. The products included in this category are too diverse (washing machines, radios, microwave ovens, etc.) to allow us to isolate here the main determinants of the evolution of copper's intensity-of-use index. However, we can say that although in the last decade the development of new products and a trend to replace rather than repair have caused the number of products per household to increase, the total consumption of copper by this sector has nevertheless declined, because of: substitution of copper by plastic, stainless steel and aluminum; product downsizing; and changes in design resulting in lower copper requirements. According to the U.S. Bureau of Mines, in recent years the overall reduction in the intensity of use of copper has been tempered by an increased use of electronic components and controls.[58] We cannot say whether in future the increased use of copper for such purposes will be sufficient to reverse the tendency toward a decline in the metal's intensity of use, but we rather doubt it.

Motor Vehicle Parts and Accessories (SIC 3710). The automobile industry offers copper producers four important outlets for their products: wiring; radiators; electrical and electronic equipment and accessories. Copper use within all four markets does not necessarily evolve the same way. Overall, downsizing of cars and changes in design have had a detrimental effect on copper consumption: smaller cars have shorter cables and wires and smaller radiators, and therefore, use less copper. Furthermore, during the 1970s, copper was increasingly replaced by aluminum in radiator manufacture, particularly in Western Europe. In 1983, 65 percent of new European cars were equipped with aluminum radiators, compared to only 17 percent of American cars.

However, American car manufacturers have now begun to adopt aluminum radiators and this will have a substantial effect on copper consumption by the automobile sector.[59] Even in cases where manufacturers prefer to stick with copper radiators, copper use will decrease because new technologies have arisen which enable the same degree of heat exchange to be attained with less volume of copper. On the other hand, since consumers are demanding cars that are ever-better equipped (with stereo systems, electric seats and windows, air conditioning, defoggers, etc.), the number of electrical and electronic applications is growing. This is likely to increase copper consumption by the automobile industry, and slow down the tendentious drop in the metal's index of intensity of use, unless, of course, this increase is counteracted by the miniaturization of electronic and electrical equipment, such as the use of printed circuits.[60]

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[58] Bureau of Mines (1986), *Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals*, U.S. Department of the Interior, Open File Report 27-86, Washington, January, p. 67.

To sum up, then, we learned from table 3 that the atrophy in copper consumption observed since the mid-1970s in OECD countries owes more to the slowdown of industrial activity than to a lowering of the metal's intensity-of-use index. A very notable exception to this trend has been the United States, and we have tried to explain why. The main reason is that substitution of copper electric wires and cables by aluminum, and of copper tubes and pipes by plastic, has been much more marked in the United States, where building codes and industry practices are quite flexible, than in Western Europe. We have noted that within the main market for copper (the heavy and general construction sectors) aluminum's penetration has slowed down, but that of plastics has begun to increase.

In the other sectors in which copper is used, substitution has been less of a factor in the lowering of the metal's intensity-of-use index. As we have mentioned, downsizing, the miniaturization of electronic and electrical equipment, multiplexing in telecommunications and the adoption of copper-saving technologies in the production of heat exchangers appear to have played a more significant role than inter-material or intra-metal substitution in the decrease of copper consumption in the production of air conditioning and heating equipment, household appliances and motor vehicle parts and accessories. The exception to this finding is car radiators; the substitution of copper radiators by aluminum ones is increasing in the United States and approaching the levels observed in Western Europe.

What will happen to copper consumption during the next few years? We can foresee its growth slowing down as a result of substitution of copper by plastics in the construction sector and by optical fibres in telecommunications. However, we expect the negative effects of substitution to be counteracted by

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[59] It is expected that more than 50 percent of radiators in 1988 model cars will be made of aluminum.

[60] If we look at the production of other means of transportation, say shipbuilding, the likelihood of the intensity of use of copper diminishing is quite small. The main danger here is the ever-shrinking demand for ships.

the growth of copper's market share in some segments of the construction sector (roofing, building wire, sprinkler systems, etc), an increase in the number of appliances owned per household, a greater use of electronic and electrical components in car production, and the development of certain other markets (heat pumps for the heating and cooling of homes and buildings, solar power, electric vehicles and desalination plants, superconductors in which copper oxides form a basis for some ceramic mixtures). If we try to look ahead to 1995, we can say that the negative effects of substitution appear likely to be stronger than the positive effects of increased copper use in specific markets, unless, of course, unexpected new uses of the metal are developed.

Nickel

Although man has used nickel unknowingly for centuries in the fabrication of weapons and agricultural equipment and for striking coins, the metal's chemical properties were not isolated until about the mid-18th century, when scientists came to understand why adding nickel to iron and steel substantially strengthened them and increased their resistance to wear, corrosion and heat. The economic development of nickel dates back only to the beginning of the 20th century, when stainless steel began to be widely used in Europe. Nickel's use during the 1920s and 1930s in the production of alloys resistant to wear and to heat, the reconstruction of Europe after the Second World War, and the industrialization of Japan have each in turn helped to assure it an annual growth rate higher than that of the index of industrial activity. During 1960-73, nickel consumption increased by 6.4 percent per year.

However, around the mid-1970s, that growth stopped, affected by both the economic recession and a lowering of the index of intensity of use. The lowering of the intensity-of-use index was caused by the replacement of nickel by various substitutes (plastics, coated steel, reinforced fibres, aluminum, platinum, cobalt, titanium and even copper), government regulations which attempted to reduce energy consumption by reducing the weight of cars, miniaturization and plastics which have reduced the nickel requirements for appliances and other consumer durables, and the like. The simultaneous effect of all these factors has been to reduce the average rate of growth of nickel consumption in OECD countries during 1973-87 to 0.8 percent per year. The United States and the United Kingdom even showed a negative growth, -1.4 percent per year.

Table 3 showed us that the structural causes responsible for the decrease of nickel's intensity-of-use index have played a greater role in the atrophy of the metal's consumption than cyclical ones affecting the evolution of industrial activity. This is particularly so in the United States and Japan; in Western Europe, the opposite has been true. In this section, we will attempt to identify those structural causes. The markets for nickel have traditionally been described as first-use and end-use markets. *First-use markets* include the industries in which nickel is combined with other raw materials in the production of engineered materials to be used later for manufacturing. In 1986, the shares of the market held by these industries were as follows:[61]

	percent
stainless steels	50
nickel alloys	16
plating	12
alloy steels	11
foundry alloys	4
copper alloys	4
others	3

Thus, about 70 percent of the nickel consumed annually in Western countries (around 500,000 tonnes) is used in the production of stainless steel and of heat-resistant steels, while the balance is used to produce alloy steel.

End-use markets include the thousands of applications for which the engineered materials produced in first-use markets are used. The Nickel Development Institute classifies them into eleven industrial sectors. This is how nickel consumption was distributed among those sectors in 1986:

		Percent
Capital Industries Group		25
Chemical Industry	9	
Petroleum Industry	5	
Power Industry	5	
Process Industry	6	
Consumer products		25
Construction equipment, machinery & transport		14
Automotive		10
Building & construction		7
Electronics		5
Aerospace		4
Marine		2
Chemicals		2
Coinage		1
Others		5

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[61] Nickel Development Institute, "The Markets for Nickel," undated brochure, Toronto.

These end-use markets can be grouped together in various ways. We can say, for example, that about 40 percent of the nickel used serves in the production of consumer goods (cars, refrigerators, other household appliances, pots, pans, plates, forks, knives, etc.), while the largest proportion of the metal is used for the production of such capital goods as commercial and industrial buildings, industrial machinery and equipment.

Only partial statistical data are available on the historical evolution of nickel consumption within each of the end-use markets mentioned above. We know, for example, that the electronics industry has seen its share of the market jump significantly compared to 1974, to a level of 5 percent, and that the automobile industry's share has declined during the last decade to 10 percent.[62] This decline can be attributed to a 30 percent decrease in nickel consumption per car produced in North America (bumpers no longer absorb a pound of nickel per unit), although, at the same time, there has been a penetration of nickel-containing steels into the gear-box production process.

The absence of consistent, historical statistical data on nickel consumption in the West by end-use markets is not a serious problem, as a large portion of Canadian nickel goes to the United States, which imports more than 70 percent of the nickel it uses. American statistics on nickel consumption are quite detailed and complete, even if they are not organized in the same manner as we presented above. Table 7 shows the consumption of nickel by the main consuming industries in the United States, classified according to the SIC code, for the years 1974, 1979 and 1984. We see that during 1974-84, American consumption of nickel decreased by just over 4 percent per year, finally stabilizing at 124.2 thousand tonnes (189.2 tonnes in 1974). To try to identify the structural causes of this decline, we will examine nickel's major end-use markets: contract construction (SIC 1500, 1600, 1700), chemical and allied products (SIC 2800), fabricated metal products (SIC 3400), machinery, except electrical (SIC 3500), electrical and electronic equipment (SIC 3600) and transportation equipment (SIC 3700). These six sectors have accounted on average for just under 90 percent of the American consumption of nickel during the period being studied. An examination of these markets has already been largely carried out by the U.S. Bureau of Mines.[63] Here are its main results:

Contract Construction (SIC 1500, 1600, 1700) and Chemicals & Allied Products (SIC 2800). These two markets are quite marginal, for they represent, on average, only 6 percent of American nickel consumption. For the past decade or so these sectors' market shares have been falling, and the annual growth rates

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[62] J. P. Schade (1987), "The Challenge of the Marketplace - The Response of the Nickel Industry," *Materials and Society*, vol. 11, no. 2, pp. 222 and 229.

[63] Bureau of Mines (1986), *Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for Twelve Major Metals*, U.S. Department of the Interior, Open File Report 27-86, Washington, January, pp. 85-95.

Table 7:
U. S. Nickel Consumption by Class of Customers: 1974, 1979, 1984 (thousand tonnes and percent)

SIC	Use	1974	1979	1984	CAGR[a] 1974-84
1500-1700	Contract construction	7.1 (3.8%)	6.3 (3.5%)	3.9 (3.2%)	-5.7%
2800	Chemicals and allied products	4.7 (2.5%)	3.4 (1.9%)	2.3 (1.9%)	-6.8%
3400	Fabricated metal products	72.7 (38.4%)	68.0 (38.2%)	51.0 (41.1%)	-3.5%
3443	Fabricated plate work (boiler shops)	12.2	11.4	8.1	-4.0%
3462	Iron and steel forgings	3.9	4.7	3.3	-1.8%
3471	Plating and polishing	23.8	25.9	22.5	-0.6%
3500	Machinery (except electrical)	32.4 (17.1%)	30.9 (17.4%)	20.0 (16.1%)	-4.7%
3511	Turbines and turbine generator sets	6.6	7.4	5.4	-2.0%
3562	Ball and roller bearings	1.4	1.2	0.7	-6.0%
3585	Refrigeration and heating equipment	1.4	2.8	1.7	2.0%
3600	Electric and electronic equipment	21.9 (11.6%)	17.5 (9.8%)	12.1 (9.7%)	-5.8%
3631	Household cooking equipment	1.4	1.7	1.2	-1.3%
3634	Electric housewares and fans	2.5	2.8	2.0	-2.3%
3673	Electron tubes, transmitting	3.8	3.6	2.6	-3.9%
3700	Transportation equipment	27.8 (14.7%)	29.5 (16.5%)	20.6 (16.6%)	-3.0%
3714	Motor vehicle parts and accessories	4.2	3.9	2.4	-5.3%
3724	Aircraft engines and engine parts	13.5	7.8	5.7	-8.3%
3731	Ship building and repairing	3.8	3.8	1.6	-8.1%
Sub-Total (SIC 15, 16, 17, 28, 34, 35, 36, 37)		166.6 (88.1%)	155.6 (87.4%)	109.9 (88.5%)	
Total U.S. nickel consumption		189.2 (100.0%)	178.1 (100.0%)	124.2 (100.0%)	-4.1%

[a] CAGR: Compound annual growth rate

Source: table derived from U.S. Department of Commerce (1986), *The End-Use Markets for 13 Nonferrous Metals*, Nonferrous Metals Division, Office of Metals, Minerals and Commodities, Washington, June, p. 34.

of these sectors (respectively -5.7 percent and -6.8 percent) have declined more rapidly than the growth rate of total nickel consumption (-4.1 percent per year). Although this decline can be partly attributed to the economic recession, the main factors are structural.

In the construction sector, nickel is used as an alloy with steel for the fabrication of structural shapes that serve as support frames for storage tanks and bridges and for the internal structure of commercial and industrial buildings. However, nickel demand for this application has declined because of increasing substitution by concrete; the use of precast as opposed to in-situ steel reinforced concrete saves appreciable amounts of time. Nickel is also used in the fabrication of stainless steel, which serves in construction for siding on building exteriors, outdoor and indoor stair railings, window frames and other corrosion-resistant decorative purposes. In this application, nickel-bearing stainless steel has been replaced not by another domestic material, but rather, by cheaper imports. Since, as we pointed out earlier, statistical data on nickel consumption do not account for the metal contained in imports of intermediary or manufactured products, the absorption of nickel and thus its intensity-of-use index are in this case underestimated.

In the chemical products sector, nickel is used mainly as a catalyst in the hydrogenation of edible fats and oils, and as a mordant to fix dyes to fabrics. Nickel consumption in hydrogenation has decreased, partly because of changes in the attitudes of consumers, who are rejecting high-cholesterol fatty foods for those less likely to cause cardiovascular illness, and partly because new technological developments now make possible greater recycling of the catalysts used in the hydrogenation process. In the dyeing process, nickel consumption has also decreased, in this case because of growing imports of textiles and clothing, which have reduced the demand for the primary materials required for the fabrication of these products.

Fabricated Metal Products (SIC 3400). This is an important outlet for American nickel, absorbing, on average, about 40 percent of the metal available. The consumption of fabricated metal products has declined less rapidly (-3.5 percent per year) than nickel consumption as a whole. This sector is vast, encompassing products as variable as shipping containers, cutlery, kettles, and the other metal products that can be found in hospital and other institutional kitchens, in dairies and in chemical processing plants. Also included here is the plating and polishing sector, which in itself accounts for more than 15 percent of total American nickel consumption.

Nickel consumption in the fabrication of metal products decreased from 72.7 thousand tonnes in 1974 to 51 thousand tonnes in 1984, a drop of more than 40 percent. The reasons for this decline are many, including the increase in imports of stainless steel mill products. Also a significant factor has been the substitution of nickel by plastic and aluminum in plumbing fixtures and fittings, and automobile bumpers and side trims. The negative effects of such substitution became particularly apparent when North American car manufacturers began to reduce the volumes and weights of their products by increasing their use of lighter materials.

Within the plating sector, steel cans are sometimes singled out as a potential growth area for nickel plating. We do not really think so, however, because although the steel cans' share of the metallic food containers market remains substantial, that end-use market is in decline by comparison with that of beverage cans. The main reason for the decline is the change in consumer behaviour toward eating more meals in restaurants, rather than at home, and consuming TV dinners.[64] Furthermore, now that aluminum cans have totally displaced steel cans in the beverage container market, aluminum producers are likely to aggressively pursue the food can market. An interesting development in this regard is the use of a liquid nitrogen injection system with aluminum cans. A drop of liquid nitrogen is introduced into the filled can before the container is closed and sealed. After the end is seamed on, the nitrogen vaporizes and expands. This technique increases the resistance of aluminum cans, enabling them to better withstand any shocks they may incur during transport or storage.

Machinery (Except Electrical) (SIC 3500). In this sector, nickel consumption fell from 32.4 thousand tonnes in 1974 to 20 thousand tonnes in 1984, a decrease of more than 50 percent. Given this decline, which is greater than that of total nickel consumption during this time, it is not surprising that machinery's share of the market has also decreased. The main cause for the decline appears to be substitution, with stainless steel being replaced by less expensive plated steels, and nickel-free specialty steel being used increasingly in manufacturing processes. Thus, although the substitution is occurring within the steel family, it is still causing a decrease in the consumption of nickel. We should note, however, that the refrigeration and heating equipment sector and the turbine sector have performed relatively well, with annual growth rates (2 percent and -2 percent respectively) above that of the machinery sector as a whole.

Electrical and Electronic Equipment (SIC 3600). Over a ten-year period, nickel consumption by the fabricators of electrical and electronic equipment dropped almost by half, showing an annual growth rate of -5.8 percent. The particularly marked decline in recent years is partly explained by the slowdown in conversion to nuclear power and the substitution of nickel by plastics in housing for electronic equipment. However, according to the U.S. Bureau of Mines, the decline in nickel consumption by this sector is unlikely to continue. There are several factors indicating that this will not result; furthermore, the trend could reverse, with increased sophistication in power generating and distribution equipment, innovations in the use of nickel powder alloys in transformers, and replacement of copper alloys with nickel alloys in lead frames for electronic circuit boards.[65]

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[64] Even if the shift toward eating more meals in restaurants has reduced the demand for steel cans and therefore for nickel plating, we should note that on the other hand this shift has produced a fairly steady demand for stainless steel for restaurant kitchens which have a five-year replacement cycle.

Transportation Equipment (SIC 3700). Like the machinery sector, this sector absorbs about 16 percent of the American consumption of nickel, but here, the decline in consumption during the past ten years has been only 3 percent per year. Of the six nickel-consuming sectors considered up to now, this one has seen the smallest decrease in its nickel consumption. If we look at particular segments of this industry, we see that the greatest decrease in nickel use has been in shipbuilding, airplane and automobile production.

The 5.3 percent per year decline in nickel consumption in car parts is explained by the downsizing of automobiles, the elimination of nickel from bumpers, and less use of stainless steel in the production of catalytic converters. Nickel demand for plating has also declined because of substitution of nickel by plastics in the decorative components of cars.

Nickel consumption in the manufacture of airplane motors and motor parts declined from 13.5 thousand tonnes in 1974 to 5.7 thousand tonnes in 1984. Although nickel has felt some pressure from substitutes in this market, the main reason for the decrease in consumption is that a number of airlines have delayed or only partially carried out plans to renew their fleets of planes. Naval construction has had an even harder time during the last ten years than the aeronautical industry, a fact reflected by an 8 percent annual decrease in its nickel consumption.

Since 1973, nickel, along with zinc, has shown the weakest growth in U.S. consumption of all the metals here considered. Among the reasons for its poor performance have been bad economic conditions (weak growth, high real interest rates, very unstable exchange rates), which have led to shutdowns of several shipyards, declines in commercial and industrial construction and slowdowns in renewals of airline fleets, and thus, a decrease in the consumption of nickel.

When economic conditions improve, the demand for nickel will very likely increase (as it did in 1987 and even more in 1988), particularly as new applications for the metal are currently being developed. Among these are the introduction of nickel-plated terne sheets which could replace galvanized steel, the development of new powder alloys that are well-suited for the high-stress parts of aircraft jet engines and the increased use of nickel in armour plating. Greater use of nickel can also be envisaged in the production of pollution abatement and waste treatment machinery, aerospace components, machinery and equipment for urban and regional transportation systems, processing equipment for petroleum, plastics and higher quality steels, and others.

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[65] Bureau of Mines (1986), *op. cit.*, p. 93.

Nevertheless, it would be incorrect to attribute the decline of nickel consumption entirely to cyclical causes. As we demonstrated earlier, most of the decline on the American market is structural and results from a decrease in the metal's index of intensity of use brought about by its replacement by a variety of materials: plastic in the production of plumbing fixtures and fittings, automobile bumpers and side trims and housings for electronic equipment; concrete (in the place of alloy steel) in the construction of bridges and multi-storey buildings; aluminum in a number of auto parts; nickel-free specialty steel in manufacturing processes; plated steels and other materials. Other factors in the decline of the intensity-of-use index have been car downsizing, consumer preference for low-fat foods and, as suggested by an anonymous referee, the drop in U.S. fabrication activity and the switch to other countries which resulted in the growing imports of stainless steels and of manufactured products based on nickel or its many alloys.

The market losses experienced by nickel as a result of structural, rather than cyclical, causes will likely never be regained. In this section, we have identified the areas in which such losses are occurring. In the last part of our study, we will examine the implications for metal producers and governments of the evolution that has been taking place in the consumption of nickel. Now, let us look at what has been happening to lead and zinc.

Lead

This nonferrous metal is very dense, malleable (it can easily be fashioned into sheets, tubes or wires), and resistant to corrosion (when exposed to air, it acquires a thin protective film of insoluble oxide or sulfate); it is, however, a poor conductor of heat and electricity.

Lead consumption has increased over the years, with the development of new chemical and metallic uses. Among the chemical uses are: its use in the fabrication of batteries and of corrosion-resistant paints; as an antiknock agent in gasoline; the use of lead arsenate as an insecticide; and of various lead compounds as stabilizers in the production of vinyl plastics. Somewhat lesser in importance are the metallic uses, which include: the use of lead as sound insulation in the ceilings of office buildings, schools and hotels;[66] as packing for the transport of radioactive materials; as covering for underground or underwater communication cables to protect them from corrosion and mildew; for shot; for collapsible tubes containing corrosive paints or pastes; and for soldering metal cans.

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[66] Other uses of lead in the construction industry include piping, roofing, and caulking.

At the beginning of the 19th century, 22,000 tonnes of lead were consumed; in the century and a half that followed, annual consumption in the western world increased 70-fold, to more than 1.5 million tonnes. As we saw in figure 1, western consumption of lead doubled between 1950 and 1973, but, unlike the case of the other metals, the 1973 or 1974 levels did not represent the peak of consumption; that was not attained until 1979. In that year, lead consumption in OECD countries reached 3.55 million tonnes,[67] a level never since surpassed. While during 1960-73 lead consumption in the OECD countries increased annually by 3.4 percent, during 1973-87, that increase dropped to 0.5 percent per year. The decline in growth was even more pronounced in the United States and Japan, and less so in the EEC.

We can see from table 3 that the atrophy of lead consumption, like that of the consumption of copper, is chiefly due to factors of a cyclical nature, in particular, a weakening of economic activity in the OECD countries, in which the growth rate of the GDP fell from 4.8 percent per year during 1960-73 to 2.5 percent during 1973-87. This downturn in western economics slowed down the car production and construction sectors, thus causing a decline in the demand for lead for the production of batteries, anti-corrosive paints, ceiling insulation and covering for underwater and underground communication cables.

Thus, the decline in the growth of lead consumption appears more linked to the evolution of the GDP than to structural factors such as the substitution of lead by other metals or materials, or technological developments reducing quantities of lead required for individual uses. In fact, had the GDP continued to increase during 1973-87 at the same rate as during 1960-73 lead consumption would have shown a respectable growth of 3 percent per year, rather than the very modest actual rate of 0.5 percent. On the other hand, had lead's intensity-of-use index shown such a consistent increase, the growth in lead consumption would have been a mere 1 percent per year.

This pattern of greater importance of cyclical than structural factors holds true for the EEC countries and Japan, but not for the United States. In the USA, the decline in the growth of lead consumption (which dropped from 4 percent to -0.3 percent per year between 1960-73 and 1973-87) seems to have resulted less from a decline in economic growth (from 3.9 percent to 2.5 percent per year) than from a decrease of the intensity-of-use index, the growth of which fell between the two periods from 0.2 percent to -2.7 percent per year. We will identify the structural factors responsible for the decline of American lead consumption by examining the metal's principal end-use markets.

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[67] A different figure (4.2 million tonnes) is given in *Lead and Zinc Statistics*, because there lead consumption is defined differently. That source refers to the total consumption of refined pig lead, including the lead content of antimonial lead, regardless of the type of source material from which produced, i.e. whether ores, concentrates, lead bullion, lead alloys, residues, slag or scrap. Pig lead and lead alloys recovered from secondary materials by remelting alone without undergoing further treatment before re-use are excluded.

According to table 8, in 1974, five sectors of lead use (storage batteries, SIC 3691; gasoline additives, SIC 2869; pigments, SIC 2816; ammunition, SIC 3482; and general construction, SIC 1520 and 1540) accounted for 86 percent of the total American consumption of the metal, with storage batteries alone holding a market share of 53 percent. The importance of these five sectors has not decreased over time, for in the mid-1980s, they accounted for 92 percent of American consumption, with the share of storage batteries up to over 70 percent. The same five sectors are also responsible for most of the lead consumption in other industrialized countries; during 1973-86 they accounted for between 60 and 80 percent of total consumption in Japan, the United Kingdom, West Germany, Australia and France. Let us look at the five sectors in the United States:[68]

General and Heavy Construction (SIC 1520-1540). Lead consumption has decreased in all the sectors of use listed in table 8, with the exception of storage batteries. In general and heavy construction, lead use has dropped by 4 percent per year, a greater decrease than that of lead consumption overall, and the market share held by this sector has steadily diminished, dropping below 4 percent. The main reason for this decline is the substitution of lead by less expensive, lighter or less health-threatening materials, such as plastics, aluminum and steel, which have replaced lead in roofing, flashing, piping, and caulking. Lead use in cable sheathing has also diminished, as the introduction of plastics for cable insulation and sheating has made it possible to produce cheaper, lighter and smaller cables for certain applications, particularly in telecommunications. If, in future, environmental concerns regarding lead are addressed, the decline of the metal could be reversed and it could see new uses, for example, as a stabilizing agent in asphalt roofing shingles and plastic pipes. It could also find new vigour in some of its current applications, as it has done in the United Kingdom. These applications include the use of lead sheets in building for sound insulation and radiation protection.

Pigments (SIC 2816). The consumption of lead oxide for the fabrication of paints, varnishes, vitreous enamels, ceramics and chemical products such as lead chromate has steadily diminished over the years. With an annual growth

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[68] The discussion is based on the following studies:U.S. Bureau of Mines (1986), *Domestic Consumption Trends, 1972-1982, and Forecasts to 1993 for Twelve Major Metals*, U.S. Department of the Interior, Open File Report 27-86, Washington, January, pp. 69-76. See also: S.A. Hiscock (1986), "Demand Patterns for Lead and Zinc in the Mature Economies", in W.R. Bush (ed.), *Economics of Internationally Traded Minerals*, Society of Mining Engineers Inc., Littleton, Colorado, pp. 220-233; W.T. Meyer (1986), "Lead and Zinc Marketing: Something Old, Something New, Something Profitable", in W.R. Bush (ed.), *op. cit.*, pp. 234-241.

Table 8:
U. S. Lead Consumption by Class of Customers: 1974, 1979, 1984,
(thousand tonnes and percent)

SIC	Use	1974	1979	1984	CAGR[a] 1974-84
1520-1540	General and heavy construction	66.7 (4.6%)	49.8 (3.7%)	44.4 (3.7%)	-4.0
2816	Pigments	105.3 (7.3%)	90.8 (6.7%)	76.8 (6.4%)	-3.1
2869	Gasoline additives	227.8 (15.7%)	187.0 (13.8%)	78.9 (6.5%)	-10.1
3482	Ammunition	78.9 (5.4%)	53.3 (3.9%)	47.8 (4.0%)	-4.9
3691	Storage batteries	772.8 (53.3%)	814.3 (59.9%)	865.6 (71.7%)	1.1
	Other				
3351	Brass mills	18.7	18.8	7.0	-9.4
3411	Metal cans	16.1	14.5	4.4	-12.1
3555	Printing type	18.6	10.0	2.7	-17.5
3660	Communication equip.	28.8	12.5	9.4	-10.5
3710	Motor vehicles	38.6	32.7	18.2	-7.2
	Other	78.8	74.7	51.7	
Sub-total (SIC 1520, 1540, 2816 2869, 3482, 3691)		1,251.5 (86.3%)	1,195.2 (88.0%)	1,113.5 (92.3%)	
Total U.S. lead consumption		1,451.1 (100%)	1,358.4 (100%)	1,206.9 (100%)	-1.8

[a] CAGR: Compound annual growth rate

Source: table derived from: U.S. Department of Commerce (1986), *The End-Use Markets for 13 Nonferrous Metals*, Nonferrous Metals Division, Office of Metals, Minerals and Commodities, Washington, June, p. 27.

of -3.1 percent, this sector holds a market share of lead of just over 6 percent. One application of the metal particularly in decline is in lead-based indoor paints, the use of which has been restricted in several countries for health reasons. More successful has been the use of lead as a stabilizer and plasticiser in plastics and glasses, and as pigment (red lead and calcium plumbate) in the production of undercoat and anti-corrosion protective paints. An economic upturn that stimulated demand for structural steelwork would probably boost lead consumption, but this is not certain, for other methods may be developed for protecting metal structures against corrosion. Similarly, conventional TV technology (lead is used in the fabrication of the glass for picture tubes and cover plates) could be largely replaced by liquid crystal technology.

Gasoline Additives (SIC 2869). Fifteen years ago, gasoline additives constituted the second most important use of lead, holding a 16 percent share of the

U.S. market. However, efforts to cut down gas consumption and the introduction of emission control devices (catalysts) that call for lead-free gasoline have caused this market to atrophy. Since the time of the first petroleum crisis, lead use by this sector has fallen by 10 percent per year. This decline has been accelerated by the U.S. Environmental Protection Agency (EPA) regulation reducing the quantity of lead permitted per gallon of gasoline after January 1986, to 0.1 gram (the previous standard was 1.1 grams). Thus, whereas in 1980 this sector held 12 percent of the U.S. lead market, in 1986, it had only 2.6 percent, consuming less than 30,000 tonnes.[69] Lead's future in this market does not appear more promising than its recent past, for at the beginning of the 1990s lead will be totally banned from American gasoline, and foreign markets, which have been absorbing more than 50 percent of U.S. tetraethyl lead, are also likely to dry up, as more and more countries adopt standards similar to the EPA's.

Ammunition (SIC 3482). This sector, which includes the fabrication of shot and small-calibre bullets for sport weapons and lead shot for radiation shielding applications in nuclear reactors, has always been a rather marginal market for lead. Its consumption of lead has fallen by 5 percent per year, to give a market share of only 4 percent. There is no reason to expect a reversal of this downward trend, unless there is an upsurge in the construction of nuclear reactors, or a change in the habits of American sport shooters.

Storage Batteries (SIC 3691). An extreme concentration is apparent in U.S. end-use markets of lead, with the two sectors linked to the automobile industry (gasoline additives and storage batteries) presently absorbing about 80 percent of lead shipments. The storage battery sector alone accounted for 72 percent of total lead consumption in 1984, an increase from 53 percent a decade earlier. This sector is one of very few end-use markets of lead to have shown a positive growth, 1.1 percent per year; its consumption increased from 773,000 tonnes in 1974 to over 865,000 tonnes ten years later. This sector of use is large, incorporating several applications:

> The major end-use markets for lead-acid batteries are (1) automotive starting-lighting-ignition (SLI systems); (2) uninterrupted power supply (UPS) systems for hospitals, computers, and banks; (3) conventional standby emergency telecommunications and lighting systems; and (4) electromotive traction batteries for electric vehicles (EVs).[70]

Although the increase of lead consumption in the fabrication of lead-acid batteries has been exceptional under present circumstances, the increase would have been even more pronounced were it not for downsizing of automobile batteries and technological improvements in battery design, which have served to bring down lead's intensity of use. On the bright side, however, the storage battery market, unlike some of lead's other end-use markets, does not appear to be threatened by substitution, at least not in the short term. This means that lead consumption by this sector will continue to increase at a rate similar to that of car production, or even at a higher rate, if electric cars begin to be commercially produced.

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[69] *Metals Week*, December 21, 1987, p. 7.

[70] Bureau of Mines (1986), *op. cit.*, p. 72.

With lead, we see yet another metal for which the atrophy of demand cannot be explained solely by cyclical factors. It is true that the reduced economic activity of the last few years has caused a decline in demand for cars, slowed down construction and, perhaps, reduced the numbers of kilometers travelled per car, all of which has contributed to the decline in lead consumption. While with economic recovery lead consumption can be expected to revive, or has already begun to do so, a significant proportion of U.S. lead consumption will not be restored. This is the part of consumption that declined because of government regulations regarding lead additives to gasoline, downsizing of cars, technological improvements in battery design, substitution by plastics, aluminum or steel in various applications in construction, and shifting away from lead by fabricators of various manufactured products (for example in the soldering of steel foods cans) owing to health concerns on the part of consumers. These markets will not return simply with an upturn in the economy; the losses to lead producers can be compensated for only through the difficult process of developing new markets.

Zinc

Zinc is a bluish-white metal, which, when exposed to air, takes on a greyish cast from the oxide film that covers it and protects it from further oxidation. Zinc is used mainly for galvanizing laminated steel products to protect them against corrosion; this is done either by dipping into molten zinc or by electroplating. Galvanized zinc is consumed largely by the construction and transport industries, but the metal has other uses as well. In brass (an alloy of copper and zinc) it serves in the fabrication of ornamental objects, medical equipment and central heating. Zinc alloys are widely used for die-casting, especially in the automobile industry, for the fabrication of mechanical parts and decorative accessories. Laminated zinc is used in building to make roofs water-tight and for gutters. In addition to its uses as a wrought metal, zinc is used in large quantities for the fabrication of pigments and other chemical products. Zinc powders and dusts are used as reducing agents in chemical reactions, and zinc oxide is used in tire manufacture and as a pigment for exterior and interior paints, as well as in the fabrication of ceramics, cosmetic and pharmaceutical products, ground coverings, etc.[71]

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[71] Excellent reviews of the aluminum, copper and zinc industries can be found in Government of Quebec, *L'industrie minerale du Quebec*, 1985, Ministere de l'Energie et des Ressources, Quebec, 1986.

Given all these applications, world consumption of zinc has steadily increased: it grew by 2.9 percent per year during 1900-38, by 3.1 percent per year during the 1950s and by 4.7 percent per year during 1960-70.[72] However, a-metal that has a variety of uses faces the threat of substitution in each use by lighter and less costly metals or materials. In the case of zinc, aluminum and magnesium offer competition in the fabrication of die-cast parts, while plastic coatings, paints, cadmium plating and special coatings in zinc and aluminum can replace it as protection against corrosion. Aluminum, magnesium, titanium and zirconium compete with zinc in the fabrication of chemical products and pigments, and the development of long-life radial tires has reduced the need for zinc oxide in tire manufacturing.

Substitution, generally poor economic conditions and the introduction of thin-wall die casting and weight-reduction programs in the automobile industry have all had adverse effects on zinc consumption. During 1973-87, zinc consumption by the OECD fell by 0.2 percent per year; in the United States, consumption grew by -1.4 percent per year, in the United Kingdom, by -3.5 percent per year, in Japan, by 0.6 percent per year, and in the EEC, growth was null.

While this atrophy can be attributed to several causes, as mentioned above, table 3 tells us that for the OECD in general, and the United States and Japan in particular, the decline in the growth of zinc consumption seems to be caused more by structural factors than cyclical ones, while in the EEC countries, the opposite holds true. In the United States, had the intensity-of-use index evolved in the same way during 1973-87 as during 1960-73, zinc consumption would have increased by 1.9 percent per year (instead of decreasing by 1.4 percent); had a similar stability been shown by the evolution of the GDP, the growth in consumption would have differed very little from that actually observed (it would have been -0.2 percent instead of -1.4 percent).

Given the importance of structural factors for zinc consumption by the U.S. market, a market which absorbs a major share of Canadian zinc exports, it is worth examining those factors more closely. Table 9 shows the main sectors of use of zinc in the U.S. economy. We see from the table that about 60 percent of available stocks of zinc in the USA are used by five sectors: construction (29 percent), motor vehicles (23 percent), stamping (including coinage) (5 percent), heating and plumbing, and air conditioning and heating (3 percent each). The market shares held by these sectors have remained relatively stable during

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[72] These figures are taken from Hiscock, S.A. (1986), *op. cit.*, p. 221.

Table 9:
U. S. Zinc Consumption by Class of Customers: 1974, 1979, 1984
(thousand tonnes and percent)

SIC	Use	1974	1979	1984	CAGR [a] 1974-84
1500, 1610, 1620	General, highway and heavy construction	306.4 (26.2%)	286.6 (28.6%)	246.9 (29.1%)	-2.0
3430	Heating and plumbing	28.4 (2.4%)	28.7 (2.9%)	26.9 (3.2%)	-0.6
3469	Stamping (including coinage)	38.0 (3.3%)	25.8 (2.6%)	44.7 (5.3%)	1.6
3585	Air conditioning & heating	32.5 (2.8%)	31.0 (3.1%)	27.1 (3.2%)	-1.8
3710	Motor vehicles and equipment	282.5 (24.2%)	242.5 (24.2%)	193.7 (22.8%)	-3.7
	Other				
2819	Industrial chemicals	21.0	16.2	13.1	-4.7
2822	Rubber	31.4	18.8	19.6	-4.6
3429	Hardware, n.e.c.	99.7	79.9	62.0	-4.6
3530	Construction machinery	14.1	11.4	10.1	-3.3
3630	Household appliances	44.7	38.7	22.3	-6.7
3692	Primary batteries	25.4	17.7	20.4	-2.2
Sub-total (SIC 1500, 1610, 1620, 3430, 3469, 3585, 3710)		687.7 (58.9%)	614.6 (61.4%)	539.3 (63.6%)	
Total U.S. zinc consumption		1,168.2 (100%)	1,000.6 (100%)	848.9 (100%)	-3.1

[a] CAGR: Compound annual growth rate

Source: table derived from U.S. Department of Commerce (1986), *The End-Use Market for 13 Nonferrous Metals*, Nonferrous Metals Division, Office of Metals, Minerals and Commodities, Washington, June, p. 52.

1974-84, although total U.S. consumption of zinc declined by about 3 percent per year. Let us look at each sector individually:[73]

Construction (SIC 1500, 1600, 1700). The construction sector is the most important U.S. outlet for zinc. Although even here zinc consumption declined by 2 percent per year during 1974-84, this decline was less marked than that of zinc consumption in general; as a result, this sector's market share has increased slightly to about 30 percent. Zinc is used in construction mainly as a protective coating for galvanized sheets, wire, tubes and fittings.

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[73] Our discussion is based on the following sources: U.S. Department of Commerce (1986), *op. cit.*, pp. 49-52; U.S. Bureau of Mines (1986), *op. cit.*, pp. 131-139; S.A. Hiscock (1986), *op. cit.*, pp. 220-233; R.G. Eggert (1987), *op. cit.*, pp. 28-29.

It may be surprising that zinc consumption has declined in construction, since anti-corrosive zinc coatings have very few substitutes that are economical and offer comparable quality and durability. Part of the reason for the decline is the general slowdown of construction, both general construction of residential, industrial and commercial buildings and heavy construction, including railroads, street maintenance, marine construction, highway building, etc. Even had construction activity remained constant during the period under study, zinc consumption would still have diminished because of thinner coating and more efficient processing. While economic recovery will benefit zinc consumption, the levels reached will be lower than they would have been were it not for the introduction of electrogalvanized steel, which attains the same amount of corrosion protection using smaller volumes of zinc per given surface.

Heating Equipment and Plumbing Fixtures (SIC 3430). Compared to the construction and automobile industries, this sector of zinc use is rather marginal, but its share of the market is growing and now exceeds 3 percent thanks to a rate of increase of consumption (-0.6 percent per year) five times higher than that of zinc consumption in general. In this sector zinc is used as brass rod and castings in the fabrication of drains and faucets, traps, and other brass goods, and cast components in air heaters and furnaces. In contrast to the construction sector, here the decline in consumption is explained by the substitution of zinc by plastic products. Another factor in the decline is the greater use of thin-wall die-castings, which were developed to help zinc withstand competition from plastics and use significantly less zinc per part than conventional die-castings.

Stamping (including coinage) (SIC 3469). Stamping is one of very few end-use markets of zinc to show a positive annual growth (1.6 percent) in recent years. Its share of the market has increased from 3.3 percent in 1974 to 5.3 percent in 1984. The main reason for the growth is the substitution, begun in 1982, of zinc for copper in pennies. This new application reversed what was promising to be a long-term decline in the use of zinc.

Air Conditioning and Heating (SIC 3585). This sector, too, saw its share of the U.S. zinc market climb during 1974-84 to a level exceeding 3 percent, given that its consumption of the metal grew faster (by -1.8 percent per year) than zinc consumption overall. Zinc's main use in this sector is in galvanized sheet and tube, and, to a lesser extent, in brass sheet and tube and zinc die-cast parts. Although several substitutes for zinc have made their way into this market, the decline of zinc consumption can be chiefly attributed to cyclical factors linked to the slowdown of construction activity. However, increased demand almost everywhere for multi-unit dwellings (as opposed to single family dwellings) will continue to stimulate the demand for zinc, as these buildings will require systems of heating and air conditioning.

Motor Vehicles and Equipment (SIC 3710). The end-use markets we have examined so far have all increased their shares of total American zinc consumption, as their consumption of the metal grew in the period under study by more than -3.1 percent per year. This has not been the case of the sector of motor vehicles and equipment (cars, trucks, buses), for consumption there decreased by 3.7 percent per year and the market share has dropped below 23 percent. In this market, zinc is used in three forms: as zinc die-cast parts in the production of grills, handles, and locks; as brass items such as radiators, tubing and electrical fittings; and as zinc coating on steel for corrosion protection.

In all three forms, zinc consumption has decreased mainly because of structural causes. The pressure on car producers to improve the fuel efficiency of their vehicles as a result of the energy crisis led to wide-scale downsizing and weight reduction, which cut down on zinc die-castings and brass used in cars. Between 1975 and 1986, the average weight per car in the United States dropped from 3,684 to 2,722 pounds. Zinc use has been reduced because of the introduction of thin-wall die-castings and the elimination of many large, decorative zinc die-castings, or their substitution by lighter aluminum or plastic components. As a result, the quantity of zinc used per car was cut in half in a decade.

All these structural changes have adversely affected zinc consumption in this sector, but things would have been even worse for producers of the metal were it not for consumer demand for better resistance to corrosion. Beginning with the mid-1970s, consumers began increasingly complaining that car bodies often rusted through before the engines wore out. The causes of these corrosion problems were poor paint jobs on U.S. cars and an increased use of salt on roads in winter to melt snow and ice. American, European and Japanese car makers adopted several strategies for improving corrosion resistance, among them, the use of zinc-coated metals in areas particularly prone to perforation and rust.[74]

However, many engineers are skeptical about these zinc-coated steels; they

> . . . believe that coated steels are an inferior solution to some corrosion problems. Coated steels, first of all, are more difficult to paint and weld than conventional, uncoated steel sheet. In addition, coated steels have less value as scrap because of zinc impurities. The engineers' argument is that companies have jumped on the bandwagon to provide corrosion resistance and are using coated steels as a marketing ploy, even though less reliance on coated steels and greater reliance on better paint jobs and hot-wax treatments would provide more corrosion protection at lower cost.[75]

In spite of these doubts as to its efficacy, the quantity of zinc used in steel coatings has increased and may increase even more in future, as American and foreign car producers continue to extend their warranty periods. However, this increase in consumption may be counteracted by two factors. First, electrogalvanization requires less zinc per square meter than the more traditional techniques such as dipping, and this difference in zinc requirements may increase even more because of technological changes. Second, the North American car market is now characterized by an excess supply, with production capacity exceeding the present and foreseen demand by about 20 percent. Because of this saturation, zinc consumption may not reach levels as high as seemed realistic to expect only two or three years ago.

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[74] Others strategies were improved paint jobs, treating parts of the car body with hot wax, improving underseals, and placing plastic skirts around the bottom of cars.

[75] R.E. Eggert (1987), *op. cit.*, p. 29

Our survey of the end-use markets of zinc did not include all the metal's applications or all the countries in which it is used. Because we considered only the major zinc uses, we did not look at such applications as the use of zinc oxide in rubber vulcanization (mainly for the fabrication of tires) and in the production of paints, or the use of zinc sheet and strip in the manufacture of batteries, for the battery case and as plates in layer cells.

As far as countries of use, we limited ourselves to the U.S. market because of its importance as an outlet for Canadian zinc. However, let us note some differences in consumption patterns among the western countries. In Japan, in contrast to the United States and Europe, consumption of galvanized zinc increased during the period under study, while the use of zinc for die casting remained quite stable. With regard to zinc use in brass and bronze, it is the United States which stands out, showing a higher growth of consumption than other western countries. Zinc consumption for sheet and strip was much greater in Europe than elsewhere, because the metal is used in some European countries (France, West Germany, Belgium) in building, for rain gutters and pipes and for roof coverings and flashings.

Our analysis has shown that the decline of zinc consumption observed during the last fifteen years is not due solely to the drop in car production or the slowdown of construction, but also to the fact that zinc users in the automobile and construction industries have adopted resource-saving technologies in the production of die-castings and of galvanized steel. They have also replaced zinc by lighter metals (aluminum) or materials (plastics), or simply stopped using zinc as a result of changes in the design of finished products. This finding is rather similar to the conclusions we made concerning the consumption of aluminum, copper, nickel and lead. While differences of degree may exist for the five metals, we now see that we cannot simply dismiss the hypothesis that the slowdown in the growth of metals consumption is also explained by changes in the material composition of products.

That being the case, economic recovery alone cannot return consumption levels of the metals under study to what they would have been had the trends observed before the mid-1970s continued to prevail. An analogy can be made with the labour market: even a significant economic recovery does not totally eradicate unemployment in a region, because there also exists structural unemployment which is not linked to the economic cycle.

Before we consider the policy implications of our conclusions, let us recall the intensity-of-use technique, the steps of which are illustrated in figure 8. This technique suggests that the consumption of a metal is a function not only of the index of industrial activity and the material composition of products, but also of two other factors: the product composition of income and net exports of metal-containing products. We will look briefly at those two variables, comparing them from the perspective of countries rather than metals, for statistical data do not exist to make possible a metal-based comparison.

Product Composition of Income of OECD Countries

It has been suggested that a decline of the share of the manufacturing sector in a nation's GDP (or an increase of the share of the service sector) adversely affects the growth of metals consumption and thus the metals' intensity-of-use index. Certainly, the transformation of primary resources into transportation equipment, food and beverage cans, electric wires, newsprint or steam generating stations appears at first sight more intensive in metals than banking or commercial activity, or research and teaching. We say "appears" because this is not always the case; much depends on how the term "service" is defined. As Vogely has pointed out,[76] a large proportion of the growth of the U.S. service sector is accounted for by government expansion, and expenditures on schools, highways, defense, and energy research and development may be relatively resource-consuming rather than resource-conserving.

Table 10, which is based on the World Bank definition of the service sector (utilities, transportation, trade, banking, dwellings and services), shows us the inter-sectoral shifts that have taken place over the last quarter-century in the countries of the OECD. From the table we see, first, that between 1960 and 1985 the share of services in the GDP of the OECD countries increased more rapidly (from 39 percent to 49 percent) than that of manufacturing (from 21 percent to 26 percent). This may help explain why the intensity-of-use index of all the metals under study except aluminum declined during this period. Aluminum's deviation from the pattern is owing to the success of the aluminum can on the U.S. beverage container market.

Second, we see that the United States and the United Kingdom, countries in which the intensity of use of metals decreased substantially between 1973 and 1987 (table 2), derive the greatest share of their GDP from the service sector, compared to other OECD countries, while showing a share for the manufacturing sector of not more than 25 percent. In the United States, the share held by manufacturing remained very stable, while that of services climbed from 48

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[76] W.A. Vogely (1976), "Is there a Law of Demand for Minerals?", *Earth and Mineral Sciences*, vol. 45, no. 7, pp. 49-53.

Table 10:
Share of the Manufacturing (M) and Service (S) Sector in the GDP of OECD Countries: 1960-85 (percent)

	1960		1965		1973		1980		1985	
	M	S	M	S	M	S	M	S	M	S
OECD total	21	39	24	42	27	46	26	50	26	49
United States	23	48	25	47	26	50	24	55	23[b]	57[b]
Japan	22	43	23	46	33	50	38	52	45	52
EEC[a]	24	40	25	40	28	45	26	48	25	49
United Kingdom	28	50	28	51	28	54	23	58	21[c]	60[c]
France	23	39	25	40	30	41	29	45	28[c]	46[c]
F.R. Germany	37	37	39	37	41	37	39	41	38	43[c]

[a] EEC: Belgium-Luxembourg, Denmark, France, Federal Republic of Germany, Greece, Ireland, Italy, Netherlands, United Kingdom.

[b] 1983.

[c] 1984.

Source: World Bank Data Tape, 1987 edition, Washington, 1987.

percent in 1960 to 57 percent in 1985. In the United Kingdom, the service sector also grew significantly, but there, manufacturing declined from 28 percent to 21 percent.

Third, the table shows us that in Japan and West Germany, countries in which the metals' intensity-of-use indices have shown a lesser propensity to decline, the share of the GDP of the manufacturing sector grew during the period being studied, and the share held by services was smaller than in the USA or the U.K. The importance of manufacturing in the Japanese and West German economies is linked to their tendency to export finished goods (such as cars) that are intensive in metals.

Although the influence of inter-sectoral shifts on the consumption of metals and their indices of intensity-of-use cannot be precisely defined, it can hardly be denied. Of course, these shifts are not the only factor affecting metals' intensity of use. Also to be considered is the shifting mix of goods within individual sectors, particularly, within the manufacturing sector. As the production of high technology goods requires fewer traditional metals per dollar of value added than the production of goods for the transportation or construction industries, the growing importance of high technology products should serve to lower the metals' intensity-of-use in manufacturing.

While little statistical information is available on intra-sectoral shifts within the manufacturing sectors of OECD countries, some such data does exist in relation to the United States. R. Z. Lawrence (1984)[77] has calculated the share of value added of U.S. manufacturing for high technology and other types of manufacturing industries for the years 1960-80. According to his calculations, the share in manufacturing of high technology goods[78] has increased from 27 percent to 38 percent between 1960 and 1980, while during the same period, goods intensive in capital, labour or resources all saw decreases of their market shares.[79]

These intra-sectoral shifts, then, work together with inter-sectoral shifts to modify the product composition of income and the intensity of use of metals, and thus help lower the metals' levels of consumption. Intra-sectoral shifts appear to be important in the American economy, but we do not know their levels of significance in other OECD countries, or how they might help explain the lower intensity of use of metals found in the United States and the United Kingdom than in Japan or West Germany. Tilton (1987)[80] suggests that penetration by high technology products has perhaps occurred more rapidly in the USA and the U.K. than in the OECD in general.

If we go back to figure 8, we find another factor, in addition to GDP and intensity of use, affecting the evolution of metals consumption: net exports of metal containing products. Let us examine this last factor more closely.

Net Exports of Metal-Containing Products.

In chapter three we pointed to the discrepancy between *reported consumption* and *overall absorption* of metals. The former refers to the apparent consumption, which is found by adding to the domestic production of a metal the difference between the imports and exports of the metal in the same form, and subtracting from it net additions to inventories; the latter is a much larger concept, encompassing also metal contained in imported consumer and investment goods.

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[77] R.Z. Lawrence (1984), *Can America Compete?*, Brookings Institution, Washington, D.C., table 4-6.

[78] High technology industries include engines and turbines, farm and garden machinery, construction and mining technology, materials handling machinery and equipment, metal working machinery and equipment, special machinery, general industrial machinery, office computing and accounting machines, service industry machines, radio and TV equipment, aircraft and parts, scientific instruments, optical equipment, drugs and cleaning preparations, chemicals and selected chemical products, plastics and synthetics, miscellaneous machinery, electrical and industrial equipment, lighting equipment and electrical components and accessories.

[79] The share held by capital-intensive industries (such as household appliances, motor vehicles and equipment, and metal containers) dropped from 32 percent to 27 percent between 1960 and 1980, while that of labour-intensive industries (apparel, footwear, household furniture) declined from 13 percent to 12 percent and that of resource-intensive industries (food and kindred products, lumber and wood products, and stone and clay) fell from 28 percent to 23 percent.

[80] J. E. Tilton (1987), *op. cit.*, p. 59.

Thus, the two concepts do not measure the same reality. If it happens that more metal is contained in a country's imports of consumer and investment goods than in its exports of such products, its absorption of the metal will be higher than its reported consumption and thus consumption and intensity of use will both be underestimated. This is probably the case for countries that are major importers of metal-containing manufactured products, such as the United Kingdom, Canada and Australia. On the other hand, a surplus trade balance in such products would mean a lower absorption of metal than the reported consumption, and thus an overestimation of consumption and intensity of use. This is likely to be true of Japan and West Germany, which are large exporters of metal-containing manufactured goods.

As this discrepancy in measurement can be rather large, we should try to pin it down, or at least discover in which direction it is tending. Let us look at table 11, which shows trade balances in manufactured goods for the principal members of OECD over the period 1973-85. According to the Standard International Trade Classification (SITC), there are four categories of manufactured products that are likely to contain metals.[81] We have included in the table only the last two categories (sections 7 and 8), because they are more intensive in metals than the products in the first two categories (sections 4 and 5). The table also shows the total trade balances for all manufactured products grouped in sections 5 to 8.

A number of tendencies can be discerned from the table. First, after experiencing a period of relatively balanced trade in manufactured products (with deficits or surpluses at just a small percentage of total exports or imports), the United States saw its trade situation deteriorate in the early 1980s, as it moved from a trade surplus of U.S. $5.2 billion in 1981 to a deficit of U.S. $113 billion three years later. Although during the whole period under study the USA had a trade deficit for miscellaneous manufactured articles (section 8), that deficit was relatively small during the 1970s; it increased in the early 1980s to reach,

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[81] Section 5: Chemicals and related products (organic and inorganic chemicals; dyeing, tanning and colouring materials; medicinal and pharmaceutical products, etc.). Section 6: Manufactured goods classified chiefly by material (leather, rubber manufactures, paper, textile, yarn, iron and steel, non-ferrous metals, etc.). Section 7: Machinery and Transport Equipment (specialized machinery and equipment, metalworking machinery, office machines and automatic data processing equipment, electrical machinery, road vehicles, etc.). Section 8: Miscellaneous manufactured articles (furniture, footwear, professional and scientific instruments, photographic apparatus, printed matter, etc.).

Table 11:

Net Exports of Manufactured Goods: Selected OECD Countries, 1973-85
(U.S. $ billion current)

Country and SITC section	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
France													
7[a]	1.9	2.5	7.0	6.0	7.8	8.4	11.1	8.0	7.0	4.1	5.5	6.7	5.3
8[b]	0.2	0.0	0.0	-0.9	-0.9	-0.8	-1.7	-2.2	-2.2	-3.0	-2.7	-2.1	-2.1
Total[c]	2.3	3.5	9.4	5.4	9.0	9.9	11.5	28.3	8.8	3.4	6.3	8.9	7.3
Federal Republic of Germany													
7	21.8	27.6	28.8	32.7	37.1	41.4	46.2	50.4	46.5	50.7	43.7	43.4	48.3
8	0.1	0.1	-1.1	-0.8	-1.0	-1.5	-2.6	-3.8	-2.3	-1.0	-1.2	-1.1	0.3
Total	28.7	42.5	38.7	42.1	46.9	53.7	59.1	63.2	61.7	67.5	58.7	59.5	67.5
Japan													
7	15.0	21.0	23.6	31.8	40.5	52.6	51.4	67.5	84.9	77.5	84.8	103.0	108.6
8	1.9	2.0	2.4	3.7	5.3	3.7	2.8	5.4	6.8	5.7	6.9	7.4	8.0
Total	23.5	38.0	41.7	51.2	63.0	74.8	72.6	95.1	116.4	104.6	110.9	128.5	134.7
United Kingdom													
7	3.6	5.1	8.2	6.7	7.0	5.9	4.3	9.3	5.8	3.0	-3.0	-3.0	-2.7
8	-0.5	-0.4	-0.2	-0.2	0.2	-0.4	-1.7	-1.5	-2.8	-2.7	-2.9	-3.4	-2.7
Total	3.8	4.2	8.6	7.9	9.6	7.5	3.6	8.9	3.6	0.3	-7.7	-8.4	-7.2
United States													
7	6.8	13.5	21.5	18.7	14.5	8.0	12.7	19.0	21.2	10.9	-6.6	-33.4	-47.6
8	-4.3	-4.1	-3.6	-6.0	-7.5	-10.3	-9.8	-8.5	-11.0	-13.8	-18.5	-29.7	-35.9
Total	-0.3	7.3	18.9	11.1	1.9	-12.1	-2.1	12.2	5.2	-10.7	-38.2	88.6	-112.8

[a] Section 7 of the Revised SITC covers the international trade of Machinery and Transport Equipment, i.e., power generating machinery and equipment, machinery specialized for particular industries, metalworking machinery, office machines and automatic data processing equipment, telecommunications and sound recording and reproducing apparatus and equipment, electrical machinery, road vehicles and other transport equipment.

[b] Section 8 of the Revised SITC covers the international trade of Miscellaneous Manufactured Articles, i.e. furniture, travel goods, articles of apparel and clothing accessories, footwear, professional and scientific instruments, photographic equipment.

[c] Section 7 and 8 defined above, plus Section 5 - Chemicals and Related Products (organic and inorganic chemicals; dyeing, tanning and colouring materials; medicinal and pharmaceutical products, essential oils and perfume materials, manufactured fertilizers, explosives, artificial resins and plastic materials) and Section 6 - Manufactured Goods Classified Chiefly by Material (leather, rubber manufactures, paper, textile yarn, non-metallic mineral manufactures, iron and steel, nonferrous metals and manufactures of metal).

Source: table derived from OECD, Department of Economics and Statistics, *Foreign Trade by Commodities*, OECD Publications, Paris, various issues.

in 1985, $36 billion. The trade balance for machinery and transport equipment (section 7) has had an uneven evolution; it was surplus until 1983, then began to show a deficit which has outstripped that of miscellaneous manufactured articles.

As the United States imports more metal-containing products than it exports, it can be assumed that its reported levels of consumption underestimate the total absorption of metals, for they fail to take into account indirect consumption via net imports of manufactured products. The size of this discrepancy increases with time. Also underestimated are the indices of intensity of use, and thus the atrophy of American metals is less marked than the standard measures of consumption would indicate. However, this is not necessarily good news for North American producers, for the additional consumption is of products produced abroad. As we have no data on the material composition of American imports of metal-containing products, we cannot say whether the discrepancy in measurement of consumption applies more to some metals than to others.

The second tendency made clear by the table is that for Japan and West Germany, the situation is the reverse of that in the United States. For the whole period under study, these two countries had surpluses in their trade of manufactured products: West Germany's surplus doubled during that time to reach almost U.S. $70 billion, while Japan's increased six-fold, to reach U.S. $135 billion. The surpluses are due mainly to these countries' exports of machinery and transport equipment, which accounted for 70 percent to 80 percent of their total trade surpluses in manufactured products. Given these facts, we can assume that measures of Japanese and German consumption of metals overestimate their total absorption, for they fail to exclude the metals used in manufactured products that are exported and thus consumed by other nations. A similar discrepancy exists in measures of intensity of use. These discrepancies are present for the whole period being studied and tend to increase with time. Again, we do not know to what extent they apply to each individual metal.

While it is often believed that the United Kingdom suffers from chronic major deficits in its trade of manufactured products, table 11 shows this is not so. On the contrary, the U.K. was in a surplus situation (under U.S. $10 billion) up to 1982, when it began to show a deficit of about the same size as the former surplus. Only in its trade in miscellaneous manufactured articles has the U.K. had a chronic deficit, but it was generally too small to take away from the surplus of the trade in machinery and transport equipment. Since 1982, however, the situation has changed, with deficits appearing in the trade of both categories of products. This means that there has not been an underestimation of metals consumption in the United Kingdom for the whole of 1973-85; in fact, the discrepancy tended to be in the other direction. However, since 1982, there has been a growing underestimation of consumption and of intensity of use, as the U.K. has imported more metal-containing products than it has exported.

Since the underestimation is a recent phenomenon, we cannot guess at the trend for the future.[82]

In this chapter, we demonstrated that the atrophy observed in recent years of the consumption of aluminum, copper, lead, nickel and zinc in OECD countries cannot be attributed solely to the economic slowdown that set in after 1973. In fact, for several of the metals, structural factors prove more important determinants of consumption than cyclical ones. This is particularly true of the United States and Japan, and less so of the countries of the EEC.

Once we established those facts, we documented the reasons for changes in the metals' intensity of use indices by showing for each principal end-use market of the five metals the relative importance of inter-material or intra-metal substitution, the increasing use of metal- or resource-saving technologies and changes in the design of finished products. We also found that decreases in metals' intensity-of-use are caused not only by variables like the above, which determine the material composition of products, but also by those affecting the product composition of income. These variables (intra-sectoral and inter-sectoral shifts) were examined in relation to the principal industrial countries. Also, we adjusted our findings regarding metals consumption by demonstrating that the measured indices of intensity of use were clearly overestimated for Japan and West Germany, and underestimated for the United States. Finally, we mentioned in the last footnote that given the way secondary consumption is treated, the reported figures understate intensity of use on the part of final consumers. The bias varies among the metals considered: it may be quite small as in the case of lead and zinc, or quite substantial as in the case of aluminum. Next, we will consider the policy implications of our findings, both for governments concerned with nonrenewable resources and for Canadian mining and metallurgical companies.

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[82] It is accepted that if we want to reflect intensity of use on the part of the consumers of final goods, then our data on apparent consumption should include secondary metal produced from old scrap and not new scrap since in the latter case it would involve double counting.

However, as mentioned early in this study, our data on the consumption of aluminum, nickel and zinc relate to primary metal. For copper, scrap used directly by ingot makers and brass mills is not counted, while scrap used to produce refined copper is. In the case of lead, all the metal (soft lead and antimonial lead) used at primary and secondary plants for the production of refined lead is included. Given such different treatment of the secondary metal consumption, we may wonder to what extent this influences the intensity of use of these metals at the final stage of consumption.

This question has been tackled by Hutchison and Tilton (1987) in the case of copper and by Tilton (1987) for the other metals. Their results can be summarized as follows:

In the case of copper, the conventional data tend to under report the intensity of copper use at the final stage of consumption. This under estimation was about 17 percent in 1960, 5 percent in 1973, and 12 percent in 1984.

For aluminum, the inclusion of secondary consumption substantially increases the level of intensity of aluminum use, in many instances by 30 percent or more. However, the relative ranking of individual countries is not altered. We should note that the secondary figures include aluminum produced from new as well as old scrap, while in order to reflect intensity of use at the final stage of consumption we should exclude the former and only include the latter.

In the case of nickel and zinc, the reported figures also understate intensity of use on the part of final consumers, but because of a lack of data we don't know by how much. The bias should be quite small for zinc (the share of old scrap in total U.S. zinc consumption for 1985 was only 8 per cent) and somewhat more important for nickel.

The interested reader is referred to: R.S. Hutchison, and J.E. Tilton (1987), "Is the Intensity of Copper Use Still Declining in the U.S.A.?", *Natural Resources Forum*, vol. 11, no. 4, 1987, pp. 325-334; J.E. Tilton (1987), *op. cit.* pp. 32-35.

5. Policy Implications

It is always with some trepidation that an economist approaches the question of the policy implications of his work, for he is by training more inclined to make analyses than to deal with their implications. At the time of this writing, furthermore, tackling the question of policy implications seems particularly risky.

Nickel and aluminum prices have just reached historic levels (respectively above U.S. $5 and $1 per pound) and the price of copper has begun to recover after falling from the peak it had attained at the beginning of the year (above U.S. $1.50/lb). This phenomenal rise in the prices of certain metals is largely the result of increased demand caused by a revival of economic activity in the countries of the OECD;[83] also contributing to the rise is the fact that in the last few years real metal prices have been so low. The relatively moderate economic recovery has come at a time when stocks of the metals are very low and markets for some of them (in particular nickel) are suffering disruptions of supply. It would be unfortunate if the increases in price were to lead producers to conclude that metals have regained the markets they had lost to substitutes, if producers failed to take the necessary lessons from the severe atrophy of the demand for their products that occurred during the last fifteen years. Should producers take such an attitude, there would be little point in discussing the policy implications of the atrophy.

A failure on the part of metals producers to recognize the structural causes of the atrophy of demand would be dangerous in the long term. Even markets that appear very stable can easily slip away, and buyers who have switched from metals to alternative materials (industrial ceramics, plastics, composite products, etc.) will not be readily lured back because of the high costs of switching. Even if we accept that part of the recent increase in metals demand may be the result of regaining some markets that had been lost previously (and thus not solely the result of increased economic activity),[84] the fact remains that during the last fifteen years the intensity of use of the metals has declined. Were it not for the many cases of substitution which we pointed out earlier, the growing use of metal-saving technologies, and the inter- and intra-sectoral shifts which have characterized the economy, the demand for metals, and thus their current prices, would be even higher than they are. The relative importance for a given metal of the structural changes that have occurred varies: for example, in the OECD overall, the changes have had a great effect on aluminum consumption and a significant effect on nickel and zinc, while in the United States, they have greatly affected all five metals under study.

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[83] The annual rate of growth of real GNP for OECD countries is forecasted to reach 4 percent in 1988 while it was less than 2.5 percent during the period 1973-87.

[84] An excellent treatment of the new relationship between metals consumption and economic growth can be found in J.E. Tilton (1988). It shows that given declining intensity of use, the economy must now expand by between 1 and 6 percent a year, depending on the metal and the geographical area, just to keep metal consumption from falling.

If the importance of the structural factors mentioned above is recognized, what are the consequences for the development strategy of metallurgic companies and the mining policies of different levels of government? Each company, after evaluating its own strengths and weaknesses, will reply to this question differently. Similarly, government bodies will come up with a variety of responses, after assessing the competitive position of their mining and metallurgic sector and its place in the economy as a whole. We will not presume here to speak for either industry or government; we will content ourselves with offering a few thoughts for reflection.

Structural Changes and Firm Strategy

The mining and metallurgic industry does not show the symptoms displayed by industries in decline, such as a steady decrease in the number of units sold, crumbling profit margins, a decline in spending on research and development, and a reduction in the number of competitors. We would not suggest that these companies should begin a controlled disinvestment, or rush to sell off their investments and get into the production of metal substitutes. Such a suggestion would not only be alarmist, it would constitute a misreading of the competitive position of Canadian ores and metals producers.

Still, while the mining and metallurgic sector may not be in decline, it has clearly, in recent years, reached the phase of maturity. The signs of this occurring are undeniable: sales are growing at a modest rate, more in line with the increase in industrial production, and, in some cases, lagging behind it. The battle for a market share is becoming more intense, as is international competition. New applications for the metals are proving more difficult to find. Increased production capacity poses a chronic problem. Competition increasingly occurs solely on the basis of price. Surpluses are less readily avoided by a less intense use of production capacity or by accumulating stocks. List prices are giving way to more flexible prices or spot prices which are determined daily on the metals markets. Company profits are proving less stable, while profits within the sector as a whole are showing a downward tendency. As a result of the slowdown of growth, greater experience on the part of buyers and increased technological maturity, the battle for customers is increasingly being waged on the basis of cost.[85]

If the sector has, indeed, reached the mature phase, what options are open to companies working within it?

Facing up to Facts and Changing Attitudes

It is always difficult for strategy planners within an industry to admit that competition has had a greater effect than anticipated or that our human capital has depreciated to the extent that an investment must now be made to acquire new knowledge more appropriate to the new dynamics of the industry. No one likes to find that reality has changed under his feet and that his past methods of dealing with things are no longer adequate. What makes this realization all the more difficult is that it implies the need for changes of attitude.

What attitude changes are required in the mining and metallurgic industry? Traditionally, managers in this industry have focused on reducing the costs of production by such means as discovering new high-grade deposits, increasing productivity through better training of personnel or adopting advanced technologies or new forms of management. This preoccupation stems, in part, from the engineering background of many of the managers and, in part, from their view of the demand for metals as something outside of their control. Given such an attitude, the only way to make profits is to reduce costs, the sole element in the equation that one can control.

Although a preoccupation with reducing production costs is all to the good, it is not, in itself, sufficient. Cost reduction leads to profits only if the metals are sold, and one can no longer count on metals selling themselves. A battle needs to be waged in each of the metals' end-use markets to assure that the metals remain competitive (lower price for an equivalent level of service) with their substitutes. In our view, recruiting or training managers who are as preoccupied with getting the metals onto the market as with increasing productivity is one of the major challenges the metallurgic industry will have to meet during the coming decade.

Before considering any new strategy possibilities, one must recognize that the structure of the industry has changed, that the change affects not only the supply of metals, but also demand, and that given the heated competition that exists today among different materials, it is no longer sufficient to produce for an anonymous market as one supplier among many; one must produce for very specific customers. The realization that metals must not only be produced at the lowest possible cost but also systematically marketed has not yet penetrated all echelons of the industry's management structure.

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[85] For a good analysis of the progress of a sector to maturity and of the strategies of sectors in decline, see M.E. Porter (1980), *Competitive Strategy*, The Free Press, New York, chapters 11 and 12.

In certain circles within the industry, people comfort themselves with the belief that the atrophy of metals demand is just a temporary phenomenon resulting from poor economic circumstances and overly-high real interest rates. These people also think that their only competitors are other metals producers. They fail to recognize that the competition includes all producers of materials and even producers of manufactured goods who are sufficiently powerful financially and technically to realize their threat of backward integration. The complacent views have been given louder voice since the beginning of 1988, when the prices of nickel, copper, aluminum, zinc and molybdenum reached historic levels. For those who subscribe to such ideas, the following pages will be of little interest.

However, for those who accept that the metallurgic sector has reached the phase of maturity and are willing to make the requisite attitudinal changes, what elements of strategy can we suggest for the future? Can something be done to prevent further losses by metals in their end-use markets, perhaps even to regain some lost markets — in other words, to flatten the metals' intensity of use curves? Before considering possible action, we must realize that some determinants of the evolution of a metal's intensity-of-use index are outside of the metals producer's control. The firm cannot modify the product composition of national income or impose the adoption of production techniques that are more intensive in metals. However, it can try to fight substitution through its pricing policy or to offset the effects of substitution through an aggressive R&D policy aimed at developing new uses for its product and thus replacing lost markets with new ones. Let us examine these alternatives in turn.

Pricing Policy and a Flatter Intensity of Use Curve

During the 1960s and early 1970s, the North American market for major metals was characterized by relatively stable list prices (prices set by the producers). Surplus production was dealt with by accumulating stocks or reducing utilization of production capacity; only very rarely was recourse made to pricing policy as a way of eliminating excess supplies. Although pricing policy was more likely to be applied at times when the market showed excess demand, reduction of stocks and more intense use of production capacity during these periods meant that prices rose less sharply than they would have had the adjustment been made by price alone.

The pricing policy described above makes sense when producers have market power and firms are in a position to coordinate or internalize the appropriate pricing or product decisions. Adjustment by volume rather than price is also possible when elasticity of demand is low (lower than 1 in absolute terms). In that case, it would not make sense to get rid of excess production by lowering prices, for this would mean a reduction of the firm's total revenues. Adjustment by volume is also favoured when the structure of costs is quite flexible, that is, when fixed costs are a small percentage of total costs or when the production process is easily adaptable, interruptible or convertible.[86]

As the conditions enumerated above were present to various extents on the metals markets during the 1960s and 1970s, it is not surprising that list prices were rigidly applied. Undoubtedly, the stability of metals prices helped the producers of aluminum, nickel and zinc to capture a growing share of a number of markets. During those years, consumption of the metals in most OECD countries increased at a slightly faster pace than production, and definitely more rapidly than industrial activity.

Near the end of the 1970s, the situation changed. List prices were gradually abandoned in favour of spot prices determined on the metals markets (LME, Comex). Even where list prices were maintained, they became more subject to change, reacting more and more speedily not only to increases in spot prices, but also to declines. This is something we have demonstrated in a separate study,[87] in which we tested the hypothesis that if an industry is characterized by limited competition, list prices are sensitive only to positive spot price changes, but if competition increases, negative spot price variations also affect list prices.

We did our testing using monthly data for the years 1970-84, which we subdivided into three periods corresponding to the three sections of the price cycle. We applied different lag structures to verify to what extent it was true that the greater the degree of competition in an industry, the more rapidly changes in spot prices will cause modifications in list prices. The main results of our test are as follows.

- The list prices set by copper and lead producers have since 1973 been sensitive to both increases and decreases in spot market prices. In the case of copper, the time lag of the adjustment has been decreasing. Thus, at least for copper, the results we obtained for 1977-84 show list prices to be of dubious usefulness. The same holds true for lead, especially when the market is on a downfall.
- In the case of aluminum, our results were quite different. List prices appeared to be responsive only to positive spot price changes. When spot prices dropped, list prices remained firmly fixed. It is possible that during the 1980s,

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[86] The conditions which call for adjustment either by volume or by price are very ably analyzed by R.E. Smith (1979), "A Theory for the Administered Price Phenomenon," *Journal of Economic Issues*, vol. 13, June, pp. 629-654.

[87] C. Nappi (1985), "Pricing Behaviour and Market Power in North American Non-Ferrous Metal Industries," *Resources Policy*, vol. 11, no. 3, September, pp. 213-224.

aluminum firms have been less able to exercise market power as a result of reduced ability on the part of management to coordinate conduct decisions. If this is the case, the resulting greater competition should have meant greater flexibility of list prices during the last few years and perhaps a shorter lag time. We cannot confirm whether this has been so, because our tests covered only as far as 1984.

- The list prices of zinc, rather like those of copper and lead, have responded to both positive and negative spot price variations. However, in the case of zinc, this flexibility of list price has been evident only during the last phase of the test period, 1978-84. During the earlier two phases, only positive spot price changes appeared to affect the list price.

It is not by chance that pricing policy for the major metals on the North American market has undergone a profound change. That change is the producers' response to a market structure that has greatly altered since the 1960s and early 1970s. The new conditions of the market include higher price elasticity of demand (consumers have more alternatives to choose from: imports, metal substitutes, other materials, and secondary supplies of metals) and a reduced capacity on the part of producers to coordinate their decisions (because of lesser concentration of producers, limited growth of metals consumption and production, and increased instability of market shares). As these new conditions apply more to copper, lead and zinc markets than to those of aluminum and nickel, it is no surprise that the switch from rigid list prices to spot prices has been more evident in the former markets than in the latter.

We see, then, that metals producers have, in the last few years, recognized their loss of market power and begun to make adjustments by price, rather than by volume as they had done in the past. This suggests that they have become more sensitive to consumer demand. They have recognized that as metals are only one of many materials available, the consumer has to be won over by means of prices that are competitive, while at the same time reflect the metals' relative scarcity. The change in pricing policy has helped stem the tide of substitution, and in some cases even facilitated the regaining of lost markets.[88] The fact remains, however, that the change we have seen in the behaviour of producers constitutes basically a defensive strategy, the effects of which will be felt only in the long term. In the next section we will discuss some actions that can yield more immediate results.

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[88] It is sometimes suggested that although spot prices better reflect the relative scarcity of metals, which helps buyers to make more enlightened decisions, they have the disadvantage of being more unstable, and may thus have the effect of reducing the long term demand for metals. However, this argument appears less and less convincing as buyers increasingly turn to futures markets as a means of protecting themselves against erratic fluctuations of metals prices.

Development of New Markets and Producer-Consumer Relations

An offensive strategy centred on innovation and new product development generally entails the following steps.

- Increasing the budget of the firm's research department and encouraging it to focus not only on improving the production process, but especially, on protecting existing markets and developing new uses for the metal being produced. New uses need to be developed for both alloys and fabricated or intermediary products.
- Recognizing the importance of new market development and translating that recognition into appropriate changes in the management structure. This could mean, for example, the creation of the position of executive vice-president, product research and market development. The person holding such a position would be responsible not only for sales, but also research and development, which would help bring down the barriers between the production and the marketing sectors of the organization. After all, however expertly a product is promoted, if it is poorly thought-out or subject to recall because of manufacturing error, it will never sell well.
- Facilitating the creation or assuring the financial survival of centres or institutes of research, the work of which is aimed principally at maintaining existing uses and creating new ones for a given metal in modern technology. The work done at these centres should include not only applied research, but also pure research, for although the benefits of pure research are generally felt only in the longer term, they often prove more durable and significant. Among the existing institutions that can serve as models for such centres are the Nickel Development Institute.,[89] the Canadian Copper and Brass Development Association, the Copper Development Association, the International Copper Research Association and the Aluminum Association. A study of the activities of these centres would be most useful, not only to identify the most productive, but also to compare their work with that of similar centres for other materials, particularly plastics.
- Taking other actions of various types, some of which have not been much discussed, such as paying more attention to the design and quality of products (when there is forward integration); recognizing the need to incubate new technologies and new products inside the firm, an essential stage before the firm can become a pioneer or mass marketer of such products: encouraging and facilitating the collection of reliable, homogeneous

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[89] For example, the Nickel Development Institute and some Japanese fabricators have found numerous new applications for stainless steel, e.g., in roofing, in thermos liners, in housing components (doors, frames, tubs, etc.)

statistical information and regularly publishing information about and forecasts for the supply and demand of a given metal.

All of the above strategy suggestions for regaining lost markets or, at least, maintaining existing ones are useful and worthy of adoption. Inherent in these suggestions is the idea that the total solution to the problem of metals demand atrophy can be found inside the firm. However, we believe that this is only half the story. A large part of the solution lies with the creation of a new type of relationship between the producers of metals and the consumers.

Until now, that relationship has not been very close. Producers have generally been content to develop metals and alloys under a number of forms and leave it up to the consumer to adapt these products to his specific needs, as well as develop new possible uses. It is time, however, that metals producers begin to follow the lead of their competitors (in particular, producers of plastics) and take steps to establish new types of customer relations. They might, for example, send out representatives to their major customers on a permanent basis, whose task it would be to get to know the clients' production problems, help assess alternative solutions and suggest what actions should be taken.

The problems faced by consumers of a product are not discovered by sitting in an office and reading the results of consultants' surveys. If metals producers want to liven up sales, they must stop acting through intermediaries and take a direct interest in their markets. Metals no longer sell themselves and their inherent qualities will not ensure a captive market. A climate of cooperation with the consumer, which will serve as the basis for the development of demand, can be created only if producers work closely with their customers and offer them the use of their laboratories for tests of technical feasibility, only if they try to foresee customers' future needs; and only if they offer customers products designed, engineered and manufactured to meet the market's increasingly exacting specifications. All of this is part of the firms' responsibility. Producers must not wash their hands of these concerns and relegate them to the mineral commodity organizations we mentioned above, for if the managers of metal-producing companies are not product oriented, the directors of the organizations will not be either.

Sectoral Maturity and Diversification

When we look at the evolution of the metals' intensity of use curves (figures 4 and 5), we may be tempted to advise metals producers to embark on a wide-scale diversification of their operations. Some have suggested that these firms should establish, in addition to their metallurgic sector, a sector devoted to new materials (for research and development of products using industrial ceramics, composite products, or the new polymers), a sector for the sale of technical, commercial and financial services, and perhaps a sector for the manufacture of products that have little to do with metals (battery manufacture, paper products, etc.).

We, however, regard such schemes with a good dose of skepticism. For one thing, channelling one's efforts into vast diversification projects is unlikely to stimulate demand for metals. For another, it would mean a failure to acknowledge the comparative strengths of the Canadian metallurgic industry. That the industry has strengths is beyond question.[90] These include the variety and grade of Canadian deposits, the high level of training of the work force, low energy costs, the proximity of the U.S. market and the important role of by-products, or credits, in the total costs of production. Such advantages are not enjoyed by any of the other materials we have mentioned.[91] Thus, we would suggest that the industry stick with what it does best.

Nevertheless, metals producers may stimulate metals demand, protect themselves from new competition and create a new dynamic of growth by looking for feasible ways to diversify their production. Thus, instead of producing metals only as commodities (homogeneous products for which demand growth is weak and whose supplier the consumer can change quickly and at little cost) aimed at a vast, anonymous market, producers could specialize in making products that are adapted to the very precise needs of specific clients. These products would not be something as generalized as industrial ceramics, polymers or composite products, but rather new alloys and very specific new materials based on traditional ones.

What are some examples of specific new products that meet very precise needs? We can cite the development of the new aluminum-lithium family of alloys, which, because of their cost-effectiveness, are likely to be chosen over composites for many applications in the next generation of airplanes; the aluminum-kevlar-epoxy laminate structure (ARALL), which shows an excellent combination of properties, such as greater fatigue life than aluminum, improved toughness and ease of assembly over organic matrix composites, and provides a weight saving of up to 45 percent; the production on an industrial basis by Alcan of a ceramic particle reinforced aluminum product called DURAL; Alcoa Laboratories' program in ceramic-matrix composites, etc. Aluminum producers are not alone in fabricating new specific products based on traditional materials. A large variety of metallic inputs are envisaged for the production of superconductor metals and for their various applications: barium, bismuth, calcium, copper, strontium, yttrium, etc. A similar variety of metals enter into the production of fine powders for the industrial ceramic market: alumina; boron, silicon, titanium or tungsten carbide; magnesium and silicon oxide; zirconium, etc. Other examples of metals and alloys responding to specific consumer needs to create products with promise of growth can be found in the literature published by the mineral commodities organizations we mentioned earlier.

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[90] See C. Nappi, "Changing Patterns and Determinants of Comparative Advantage in North American Metal Mining", *Resources Policy*, March 1989 (forthcoming).

[91] M.K. Murthy Consultants International (1985), *Advanced Ceramics: Technology Situation Report*, Ottawa, September.

Thus, to achieve a differentiation of products based on traditional materials in order to stimulate the demand for metals, it is necessary to combine with the production of commodities the fabrication of products which are adapted to more specific uses and respond to evolving needs. Adopting a policy to do this would have the additional benefit of serving as a new impetus to growth for the companies in the metals sector. Other forms of diversification can do that as well. The sale of technological licenses for the use of procedures developed by metals producers (like the Outokumpu process used in copper production or the Pechiney process used in aluminum production) or sales of technical, commercial or financial services can also initiate growth. However, these forms of diversification would have little positive effect on the demand for metals.

The Atrophy of Demand and Government Policy

In the view of economists of a liberal bent, healthy competition within specific industries is better for an economy than government intervention. As we tend to share this outlook, our discussion of government policy with regard to the metals industry will be rather brief. Still, it is not our belief that government has no place at all on the industrial scene. For two principal reasons, we believe that some government presence in the metals industry is justified. First, because pure research in metallurgy and industrial materials is very costly and tends to bring results that are felt only in the distant future, it is unlikely to get the required support from the private sector. Second, if a private producer does finance such research, he cannot count on profiting from his investment, for the results of the research will sooner or later be available to the whole community.

Thus, we believe that the federal and provincial governments can play an active and positive role in helping to counter the atrophy of metals demand. We suggest that they take the following steps.

First, the federal government should increase the human and financial resources of the centres and institutes of research on metals and industrial materials (industrial materials research may result in unexpected opportunities for metals) that are financed by the National Research Council. The importance of pure research cannot be overstated. Far from constituting a needless expense, as some people believe, this type of research is, in fact, the basis on which future discoveries and developments of new materials and alloys and their applications will rest.

In order to have a better match between the research done at these centres and the evolving needs of the consumers of metals and other materials, it would be advisable to develop improved mechanisms of consultation. This would not be in order to control the research that is done, but rather, to let the consumers of tomorrow have a say in the research choices that must inevitably be made.

Provincial governments, too, are involved in research activities; in the past, some of them have financed research centres devoted to the development of new uses for specific metals. When such centres are launched, care must be taken to see that they do not duplicate the activities of the mineral commodity organizations established by private companies. Government research centres should focus on pure research, unless, of course, a lack of cohesion within a particular industry has prevented the establishment of a private centre devoted to applied research or to the promotion of a metal.

Second, we have recently witnessed government attempts to encourage and help Canadian firms move to new technology, an essential move if Canadian products are to remain competitive on international markets. This encouragement takes the form of incentives for capital investment, subsidy programs and changes in government regulations and patent procedures. While the importance of technology for improved competitiveness of the mineral and metal sector cannot be doubted,[92] technology alone will not be sufficient if attention is focused solely on process technologies and not at all on development of new uses. Thus we recommend that government policies pay as much attention to the consequences of technological developments on the marketing of metals as to their effects on production. In government, as in private enterprise, what is needed most of all is a change of attitude. We recognize that government policies centred on supply aim to stimulate regional economic development and prevent the immediate unemployment that results from any closing of a mine, a smelter or a mill. However, it must be realized that unless new markets are found for the metals produced by the firms, this solution will prove only short term, and the original problems will recur.

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[92] R.A. Bonewitz of Alcoa Laboratories gives several examples of the role of technology in making products more competitive: Alloys utilized in these products will be manufactured using process technologies that reduce cost and improve quality. Highly automated ingot casting facilities, based on electromagnetic casting and employing improved metal treatment systems, will be utilized to improve ingot quality and increase recovery. Constitutive equations based on a thorough understanding of thermomechanical processes will be used to drive computer controlled production of fabricated products, and statistical process control will permit higher level of quality, as well as more consistent quality than ever before. Advanced manufacturing concepts encompassing islands of automation, computer integrated manufacturing, and direct electronic communication from customers into manufacturing operations will be essential for optimizing product quality, cost competitiveness and customer service. Implementing such technology will be essential to effectively compete in the materials industry, today or in the future. R.A. Bonewitz (1987), "Advanced Materials, Products, and Manufacturing Processes — A Challenge to the Metals Industry", *Materials and Society*, vol. 11, no. 2, p. 193.

Third, mention is often made of the fact that governments have the power to influence the demand for metals and materials by means of their procurement policies. It must be understood that governments may behave like any rational consumer and will encourage the purchase of metals or alloys only if these materials meet the needs of their specific programs. If they do not, it will be metals substitutes that will benefit from the government programs. An American example shows how this operates. The requirement by the U.S. Department of Defense for low-weight weapons and long-range aircraft created a demand for lighter materials, which led to new materials research. Thus, new U.S. materials industries arose as spinoffs of specific government objectives.

Concluding Remarks

To suggest specific policies that should be adopted by private companies or government officials is always a risky exercise. To some firms, which have already changed their strategy, such recommendations might seem redundant; to others, they might appear too general to be able to take into account each individual firm's particular situation. The recommendations we made to governments might seem contradictory, as at one moment we advocate a *laissez-faire* policy, and at another, propose that government take responsibility for the type of research that private enterprise would consider unprofitable.

Thus, rather than make specific proposals, we have concentrated on pointing to the questions that deserve further study and making some general observations and strategy suggestions. To do more would not only raise more questions than it answered, it might serve to mask an obvious truth which sometimes tends to be forgotten: *the only way that, in the long run, a material can avoid being replaced is by offering better quality than any other material that is comparably priced.* Striving for such superior quality, whether in a conventional metal or some other material, brings benefit to the manufacturing sector and to the economy as a whole. As R.F. Balazik and B.W. Klein of the U.S. Bureau of Mines stated:

> The displacement of outmoded materials by superior substitutes is a recurring theme in the history of materials science. The competitive advances made by new materials represent a classic case of a substitute that cannot be deterred in the long run if it offers superior quality not otherwise available at that price in the marketplace. It is precisely the reach for higher quality, and thereby greater competitiveness, that motivates high-tech materials development and use. The resulting increase in competition has inflicted market losses on conventional metals producers for particular end uses. However, the net result, or so-called 'bottom line' of high-tech materials substitution, is that U.S. consumers may be able to purchase better, lower cost products and American manufacturers have additional opportunities to be competitive in world markets.[93]

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[93] R.F. Balazik and B.W. Klein (1987), "The Challenge of New Materials", *Materials and Society*, vol. 11, no. 2, p. 141.

6. Summary and Conclusion

During the mid-1970s, most western countries experienced very marked slowdowns in the growth of consumption of aluminum, copper, lead, nickel and zinc. Although this turnaround was more pronounced in the United States and the United Kingdom than in Japan or West Germany, it was everywhere a cause for concern, in particular because the longest period of economic revival of the post-war era did not set the situation right. For most of the 1980s, metals markets have been characterized by excess supply and very low real prices.

In this study, we investigated the reasons for the atrophy of demand for metals, examining in detail both cyclical and structural causes. We came to the conclusion that in OECD countries in general, structural causes have been more significant than cyclical ones in the decline of the demand for aluminum, nickel and zinc. In the United States, the main market for Canadian metals exports, structural causes predominate for all five metals studied.

Although it is true that a decline in industrial activity reduces metals consumption because smaller numbers of cars, houses and general consumer goods are purchased, and therefore, produced, our results demonstrate that even had industrial activity remained constant during 1973-87, a major decline of metals consumption would still have occurred. The substitution for metals of other materials offering superior quality for a given price, a growing use of metal-saving technologies, and inter- and intra-sectoral shifts taking place in the economy as a result of changes in consumers' tastes and habits or in various government policies (fiscal, monetary, environmental) have each in turn modified the material composition of products and the product composition of income, and therefore, the consumption of metals. This finding holds true even when we make adjustments to account for metals absorption resulting from net imports of metal-containing products.

Our study did not measure the relative importance of each of the structural variables mentioned above, but such was not its intention. In any case, we doubt it would be possible to isolate the effect of each variable in relation to each of the metals studied. However, we documented and abundantly illustrated the role played by structural factors in the slowdown of the growth of the metals' consumption. To do this, we looked closely at the main sectors of use of aluminum, copper, lead, nickel and zinc. We identified many cases of substitution (for example, the replacement of nickel with plastic in the production of plumbing fixtures and fittings, automobile bumpers and side trims, and housings for electronic equipment, and the replacement of copper electric wires and cables by aluminum, and of copper tubes and pipes by plastic) and of adoption of metal-saving technologies (for example, the reduction of the weight of aluminum cans by more than 40 percent since 1960, and the increased use of electrogalvanized steel, which has led to a decline in zinc consumption because electrogalvanized steel offers the same amount of corrosion protection using a smaller volume of zinc per given surface). We also illustrated the effect on metals consumption of government regulations (such as the environmental protection legislation that has speeded up the adoption in cars of emission control devices that call for lead-free gasoline) and of changes in consumption habits (for example, the increasing market share held by unpackaged soft drinks, which limits the growth of aluminum can sales). Finally, we examined other determinants of the inter- and intra-sectoral shifts that take place in an economy (the latter type of shift occurring because the production of high technology goods requires fewer traditional metals per dollar of value added). Thus, although we were not able to precisely quantify the relative importance of each of these structural factors, our close examination of the principal end-use markets of the metals studied at least permitted us to qualify for each metal the main causes of the decline of consumption growth.

What implications do our findings have for the strategies of metallurgic firms and for government policies? We answered this question in a general way, proposing some elements of appropriate firm strategies and government policies. We noted that the switch made by metals producers from list prices to more flexible pricing during the last decade may result in a long-term flattening of the curves of the metals' intensity of use and thus prolong the industry's phase of maturity. We then gave some suggestions for a strategy that would be more active and less defensive. The first of these suggestions was to increase spending on research and development, in order to improve the competitiveness of the existing products and to develop new markets. This increased emphasis on research can take the form of enlarging internal research budgets, recognizing the importance of developing new markets and translating that recognition into changes in firms' administrative structures, and helping to ensure the financial survival of mineral commodity organizations devoted to maintaining and extending the use and effectiveness of particular metals.

Our second suggestion was that closer relations should be forged between metals producers and consumers. Metals producers should follow the example of their competitors and send out representatives to their major clients on a permanent basis. The duties of such representatives would be to get to know and anticipate customers' production problems, help assess alternative solutions and make constructive suggestions. Polymer producers and the main aluminum companies have been following this practice for the last several years, and other metals producers would do well to do the same.

Our third point was a rejection of the idea that metals producers should begin a wide-scale diversification of their production to include manufactured products, services or new high-tech materials. In our view, Canadians enjoy comparative advantages when it comes to the production of metals, and it is far from obvious that we are equally favoured for producing industrial ceramics, polymers or composite products. Nevertheless, producers of traditional metals would be well advised to differentiate their products and develop products specifically designed, engineered and fabricated to meet their customers' increasingly exacting specifications. As examples of such development of specific new products, we mentioned the fabrication of certain new alloys and very specific materials based on traditional metals.

The fourth point we made was that, although we do not believe that government should be actively involved in the metals market, there is a role for government in the funding of pure research, which is not sufficiently profitable in the short term for private enterprise to support it. We also recommended that government policy be as sensitive to the consequences of technological development on the marketing of metals as to its effects on process technologies. Fast policies have tended to focus on improvements in productivity, while ignoring the development of new products or new markets.

None of the suggestions listed above, however, mention what we consider to be the most important means for countering the atrophy observed in the consumption of metals. That is not so much a change in firm strategy or government policy, but in the attitudes of company directors and government officials. It is imperative that they begin to recognize that we are no longer living in the blissful period of the post-war era, when metals practically sold themselves, or at least were easily sold without any sophisticated marketing strategy. They must realize that for consumers today, producers of metals are one source of materials supply among many, that competition now exists not only within the metals industry, but within the whole of the materials industry. No longer (or almost) are there any end-use markets reserved exclusively for metals producers. In each of these markets all-out war must be waged, not only to regain lost ground, but even to retain the present position. Many producers have already set themselves to the task; the others must follow suit. In facing this new challenge, and face it they must, Canadian metals producers may also find unexpected new opportunities.

Appendix A

Intensity of Use Hypothesis and Measurement Problems

This appendix presents some of the measurement problems which afflict all the econometric studies using data on metals consumption and, in particular, those testing the Malenbaum hypothesis and its empirical extensions:

First, as noted by W.A. Vogely,[1] even if it is true that a decreasing proportion of national revenue is coming from the manufacturing sector, it cannot be definitely stated that the shift to services really saves mineral resources. He points out that although government activities are traditionally categorized as part of the service sector, much of the money spent by government agencies goes for the construction of schools or of highways, or for the production of armaments for national defence — resource-consuming rather than resource-saving activities. Thus, even the relationship between intensity of use (IU) and the product composition of income (PCI) is questionable.

Second, other authors[2] point out that Malenbaum's hypothesis cannot really be tested empirically because of deficiencies in existing data on metals consumption. As we noted in chapter two, the available data relate to apparent metals consumption, which is obtained by adding to the domestic production of metal ingot the difference between imports and exports of the metal in that form, and subtracting from it net additions to inventories, thus presumably getting the quantity of metal consumed during a given period. However, Malenbaum's hypothesis does not speak of apparent or reported consumption, but, rather, the overall metal absorption in an economy, i.e., the total domestic use of a metal in final consumer and investment goods. The difference between *reported* consumption and *overall* absorption consists of the metal content in net trade of semimanufactured and finished products.

If more metal is contained in imports of finished or semimanufactured goods than in exports of the same types of products, then a country's absorption of metal will be higher than the reported consumption. Such is perhaps the case in the United Kingdom. As no tabs are kept on the vast amounts of metal contained in finished consumer and investment goods imported from abroad, the U.K.'s total metals consumption and its indices of intensity of use of the metals (see figures 3 and 5) are probably underestimated. The reverse is true in West Germany, where levels of consumption and indices of intensity of use (also figures 3 and 5) are overvalued because net exports of metals contained in intermediary and finished products sold abroad are not subtracted during the calculation of the reported consumption of metals. For other countries, the difference between the two measures of consumption may be rather small. Nevertheless, the use of reported consumption rather than total absorption of metals for empirical testing of Malenbaum's hypothesis constitutes a measurement error which clearly affects the results of regression analyses.

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[1] W.A. Vogely (1976), "Is There a Law of Demand for Minerals?", *Earth and Mineral Sciences*, vol. 45, no. 7, pp. 49-53.

[2] M. Radetzki (1986), "Issues in Measuring and Forecasting Metal Consumption in LDCs", *Materials and Society*, vol. 10, no. 3, pp. 491-511; M. Radetzki and J.E. Tilton (1987), op. cit., pp. 7-9; J.E. Tilton (1987), "The OECD Countries", paper presented at the *World Metal Demand Workshop* sponsored by Resources for the Future and the Colorado School of Mines, Helsinki, Finland, October 12-13, pp. 26-38.

Of course, it is always easier to point out a problem than to correct it. Even in a country like the United States, where government statistics are very good, data on total absorption are not available for all the metals and the whole of the period being studied. Still, we should keep this measurement error in mind when studying the evolution of reported consumption[3] and, perhaps, console ourselves with the knowledge that the error is present in most studies of metals demand that use data relating to apparent consumption.

Third, two other sources of measurement error should be pointed out: net additions to inventories and accounting for secondary metal. A detailed look at this problem can be found in Tilton's excellent article;[4] we will present it only briefly. If the reported consumption of metals is to reflect the quantity of metals actually used during a given period, net additions to inventories should be excluded. However, data on inventories of unwrought metal for the OECD countries are incomplete and information on inventories of metal contained in finished or semimanufactured products is very rarely available, so the necessary correction cannot be made. With regard to secondary metal, we noted in Chapter two that for aluminum, nickel and zinc it is not included in the reported consumption, while for copper and lead it is partly included. It should be noted, however, that generally, new scrap should be excluded, as it entails double counting, but here, again, statistical data that would make the correction possible are not always available.

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[3] M.C. Roberts has recently proposed a model in which the reasons for differences in metals use among nations are, first, the differences in size of the various national economies and, second, the levels of net exports of manufactured goods. See M.C. Roberts (1987), "The Consumption of Metals and International Trade", *Materials and Society*, vol. 11, no. 3, pp. 391-406.

[4] J.E. Tilton (1987), op. cit., pp. 26-38. See also R.S. Hutchison and J.E. Tilton (1987), "Is the Intensity of Copper Use Still Declining in the United States?", *Natural Resources Forum*, vol. 11, no. 4, pp. 325-334.

Another difficulty concerns the choice of units of measure of metal consumption. Should consumption be measured in physical units, such as metric tonnes (as it usually is) or in terms of monetary value? Since metals have different physical properties and serve a variety of functions, how can we capture these quality differentials? Certainly not by looking at simple tonnage measures of aggregate consumption. Economists like T.J. Considine[5] and D. Humphreys[6] have considered these questions; in their view, the usual method of measurement fails to recognize that the mining and metallurgic industry is motivated primarily to make profits by selling products at the highest possible prices while incurring the lowest possible costs, rather than to dispose of numbers of tons of metals. Humphreys finds that the consumption of metals as measured in value has increased more rapidly than as measured in weight, which suggests that the index of intensity of use as currently determined is biased towards the low end of the scale, exaggerating the decline in metals use.

Again, correcting problems that are pointed out is not always feasible. For one thing, it cannot really be said that, apart from steel products from steel mills, the quality of refinery production has changed very much over the last few decades. The new and improved alloys and other products are still coming mainly from fabricators, not producers. Furthermore, statistical data in which metric tons are adjusted for differences in quality are not easily available for the metals and the period being studied. In any case, making such adjustments could lead to other problems, as J.E. Tilton and M. Radetzki tell us:

> In most applications, metals provide a variety of attributes - strength, appearance, corrosion, resistance, heat conductivity, and so on. Determining the appropriate tradeoffs and weights to assign to these attributes is very difficult, in part because they are not the same for all users.
>
> The case for using value to capture quality changes also has problems. The price of a metal and hence the value of its consumption may rise over time even though quality remains unchanged. No one would argue, for example, that the sharp rise in the world price of crude oil during the 1970s reflected improvements in quality. In addition to such market manipulations, metal prices can increase simply because wages and capital costs are rising. On the other hand, as the example of multiplexing indicates, new technology can enhance quality without increasing the value of metal production.[7]

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[5] T.J. Considine (1987), "Understanding Trends in Metal Demand", *Materials and Society*, vol. 11, no. 3, pp. 349-370.

[6] D. Humphreys (1987), op. cit., pp. 339-346.

[7] M. Radetzki and J.E. Tilton (1987), op. cit., pp. 11-12.

Appendix B

Roberts' Extension of Tilton's Procedure

Roberts goes back to Tilton's equation (3), but he makes a distinction between metal-containing products fabricated within the domestic market (P_{dt}) from those produced abroad (P_{mt}), thus:

$$P_{it} = b_{it}\ Y_t \tag{3}$$

but

$$P_{it} = P_{dt} + P_{mt}$$

or

$$P_{dt} = P_{it} - P_{mt} \tag{7}$$

He then reformulates equation (2) by specifying the domestic demand for metals (D_{dt}) where

$$D_{dt} = a_{it}\ \ P_{dt} \tag{8}$$

If we replace the value of P_{it} of equation (7) with that of equation (3), and if we substitute the value of P_{dt} of equation (8) by its new value, we get

$$D_{dt} = a_{it}\ (b_{it}\ .\ Y_t - P_{mt}) \tag{9}$$

So far, we have excluded the quantities of metal demanded for the production of goods destined for foreign markets (D_{xt}). Assuming that the same technology is used for fabricating products for the international as for the domestic market, we can state that

$$D_{xt} = a_{it}\ .\ P_{xt} \tag{10}$$

where P_{xt} indicates the level of production of goods destined for foreign markets at time t. If we define the total consumption of metals (D_t) as

$$D_t = D_{xt} + D_{dt} \tag{11}$$

and if we substitute (9) and (10) in (11), we get:

$$D_t = a_{it}\ .\ P_{xt} + a_{it}\ (b_{it}\ .\ Y_t - P_{mt}) \tag{12}$$

or

$$D_t = (a_{it}\ \ b_{it})\ Y_t + a_{it}\ (P_{xt} - P_{mt}) \tag{13}$$

Given that $P_{xt} - P_{mt} = P_{nxt}$ (the net value of metal-containing products destined for foreign countries), then

$$D_t = (a_{it} \,.\, b_{it})\ Y_t + a_{it}\ P_{nxt} \qquad (14)$$

Finally, if we generalize for n final goods produced in the economy during period t, equation (14) can be reformulated as follows:

$$D_t = \mathop{\varepsilon}\limits_{i=1}^{n_t} \left[(a_{it} \cdot b_{it}) Y_t + a_{it}\ P_{nxt} \right] \qquad (15)$$

This specification suggests that the influence of the level of industrial activity (Y_t) and the net exports of metal containing manufactured products (P_{nxt}) on the total consumption of a metal will depend on the value of two ratios: the product composition of income (b_{it}) and the material composition of products (a_{it}). These two values can be estimated directly: the coefficient of estimation of P_{nxt} gives us the value of a_{it}, while the value of b_{it} can be found by dividing the value of the coefficient of Y_t by that obtained for P_{nxt}.

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